Study of multilayer systems in electron beam lithography

R.F. Peters[1,2], T. Fito[1,2], L. Gutierrez-Rivera[1,2], S.K. Dew[1,2], M. Stepanova[1,2]
[1]*Department of Electrical and Computer Engineering, University of Alberta, Canada*
[2]*National Institute for Nanotechnology NRC, Canada*
ms1@ualberta.ca

Advancements in electron beam lithography (EBL) have enabled a significant number of applications requiring the versatility and high resolution of fabricated nanostructures. Emerging technologies, such as nano-photonics, nano-fluidics, nano-biosensors, and others, often require the use of alternative substrate materials compared to traditional materials, such as silicon wafers. Dielectric substrates, in particular, suffer from charging effects that significantly limit the pattern quality and resolution attainable using EBL processes employing polymeric resists. The inclusion of conductive layers extends the capabilities of EBL for such materials but can have a substantial influence on optimizing writing parameters when compared to standard EBL processes without such layers. Simulation of exposure and development conditions allows for substantial control over device fabrication and design, in particular at deep nanoscale [1,2]. In this work, we extend our electron beam lithography simulation tool [2,3] by incorporating the effects of anti-charging conductive layers on top of PMMA resist (Fig. 1) and compare the predictions with experiments employing both fused silica and silicon substrates.

The substrates were spin-coated with PMMA 950K and then coated with conductive layers of either aluminum or a conductive polymer (aquaSAVE, Mitsubishi Rayon Co.) [4]. Arrays of dots of 50 nm and 100 nm pitch as well as other patterns were fabricated using a Raith 150^{TWO} system using 30 keV voltage and a 7.5 µm aperture. After exposure, the aluminum layer was removed using CD-26 Developer (Microposit), while the conductive polymer was removed using deionized water. Samples were developed at room temperature using an IPA:Water (7:3) mixture for 20 seconds. These examples are shown in Fig. 2.

The detailed description of our simulation methodology applicable to one layer of resist on a semiconductive substrate is given in [2,3]: at any point in the resist we compute the yield of scission of polymer chains taking into account elastic and inelastic scattering effects of primary, secondary and backscattered electrons, after which the kinetic process of development is simulated. In this work, we describe analytically the additional widening of the electron beam in the resist due to elastic scattering in the conductive layer (Fig. 1b) and included this effect in the model [2,3], see Fig. 3(a,c). Excellent agreement between the simulations and experiments was seen for substrates using the aquaSAVE layer (Fig.4) indicating that our model of beam broadening is valid. Predictions for the aluminum conductive layer, however, showed significant variance from experimental results. Our investigations have revealed that aluminum sputtering damages the resist, causing up to a 40 nm reduction in resist thickness after development.

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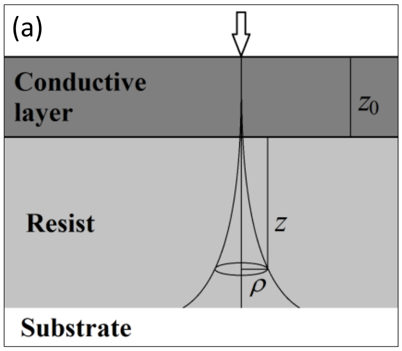
[3] K. Koshelev et al., J. Vac. Sci. Technol. B 29, 06F306 (2011).
[4] M. Muhammad et al., J. Vac. Sci. Technol. B 29, 06F304 (2011).



(b)

$$P(\rho,z)=\frac{3\lambda}{\frac{\lambda}{\lambda_0}(z+z_0)^3+\frac{\lambda_0-\lambda}{\lambda_0}z^3}\cdot$$

$$\cdot\exp\left(-\frac{3\lambda\rho^2}{2\left(\frac{\lambda}{\lambda_0}(z+z_0)^3+\frac{\lambda_0-\lambda}{\lambda_0}z^3\right)}\right)\rho$$

Figure 1. (a) – Scheme of EBL exposure of resist covered by a conductive overlayer; (b) – formula describing electron beam broadening in the resist after passing through a layer of another material of thickness z_0. In (b), $P(\rho,z)$ is the probability density to find electron at distance ρ from the axis of the beam at depth z in the resist, and λ and λ_0 are the transport mean free paths in the resist and conductive layers, respectively.

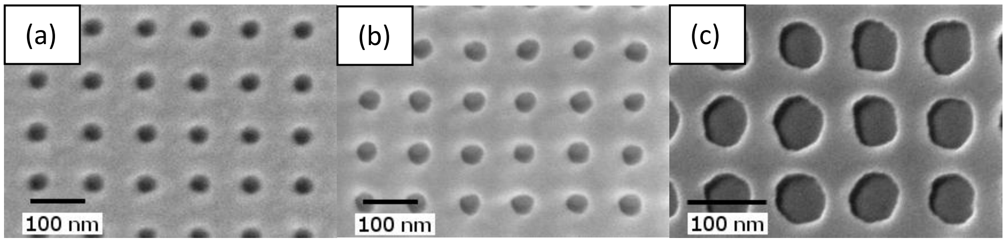


Figure 2. SEM images of 100 nm pitch dots in PMMA exposed with a 30 keV voltage and 7.5 fC/dot dose for a (a) fused silica substrate with an aquaSAVE layer, (b) silicon substrate using aquaSAVE layer, and (c) fused silica substrate with a sputtered aluminum conductive layer.

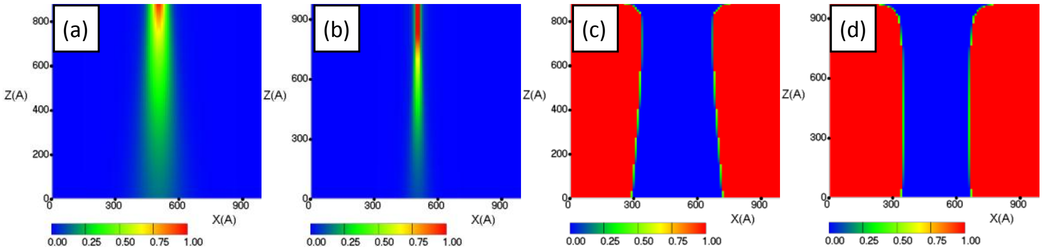


Figure 3. Examples of simulated cross-sectional profiles of the normalized scission yield (a,b) and resist development (c,d) for a 100 nm pitch, periodic dot pattern in~90 nm thick PMMA resist: (a,c) – simulation using a fused silica substrate and a layer of conductive polymer; (b,d) – benchmark simulation for a silicon substrate without a conductive layer. Development profiles in (c,d) were obtained for an IPA:Water (7:3) mixture for 20 seconds.

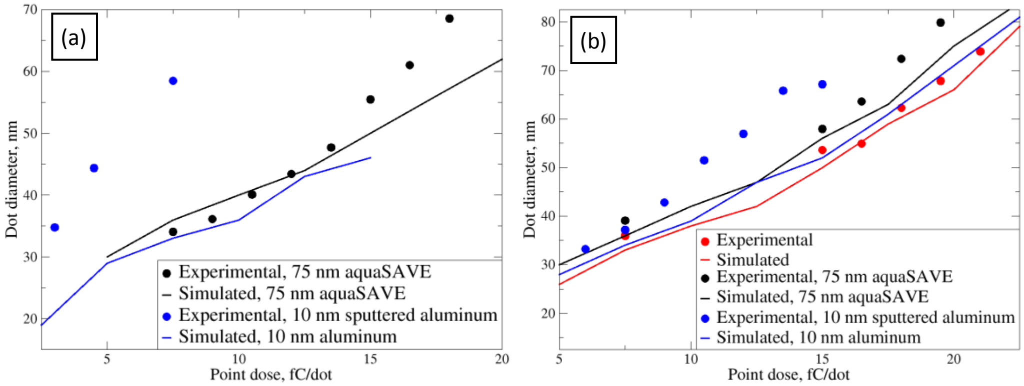


Figure 4. Experimental (dots) and predicted (lines) diameters of dots with a 100 nm pitch, fabricated in PMMA with various exposure doses for (a) fused silica substrates and (b) silicon substrates. Thickness of PMMA is between 90 nm and 100 nm in all cases.