Density Multiplication of Nanostructures Fabricated by Ultra Low Voltage Electron Beam Lithography Using PMMA as Positive and Negative Tone Resist

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Ever-increasing demand for smaller dimensions of devices for photonic and information storage applications urges to continually invent new techniques to fabricate dense arrays of nanostructures on larger chip areas. One approach that has been used to achieve this is density multiplication, when a pattern generated by electron beam lithography (EBL) is converted into a denser structure employing a directed self assembly of block copolymers [1-3]. In this work, we achieved a density multiplication of a nanoscale dot pattern in a more straightforward way that does not involve block copolymer self-assembly. We have employed a 1 keV voltage exposure (Raith 150$^{\text{Two}}$) and cold development (-15°C in MIBK:IPA 1:3) of polymethyl-methacrylate (PMMA) in the regimes where parts of the resist perform as a positive tone, and other parts are converted into a negative tone resist. Fig. 1 shows an initially 100 nm × 100 nm pitch array of single pixel dots exposed in an ~30 nm thick PMMA layer on a Si substrate using 1 keV electrons. In Figs. 1 (c) and (d), the pattern is converted into a 2 times denser array of dots of 25 - 40 nm in diameter, fabricated in a single exposure and development step. In order to better understand the underlying mechanism, we have conducted a detailed 3D modeling of exposure in PMMA employing our EBL simulator reported recently [4]. Fig. 2 shows our simulation of the spatial distribution of the yield of scission in average per PMMA monomer, at exposure dose of 0.0300 pC per single pixel dot. Scission yields larger than 1 in Figs. 2(b-d) indicate that inelastic collisions of electrons with PMMA are more abundant than required to break the resist into monomers. From our modeling results we conclude, that PMMA starts performing as negative tone resist, when the scission yield per monomer at the bottom of the resist exceeds approximately 3, and well-defined pillars of negative tone PMMA arise, when the scission yield is larger than 10-12. Such numerical predictions can be employed to design other density multiplication EBL processes. Although the present work illustrates density multiplication of dots at 1 keV, the approach could be extended to lines and other periodic patterns fabricated with other exposure voltages. More studies are presently being carried out to achieve a better control over feature dimensions, improve pattern quality, reduce the dimensions of patterns, as well as extend the approach to other patterns. This technique is very promising as a low cost, high throughput density increase by a factor of 2 in a single EBL process step.

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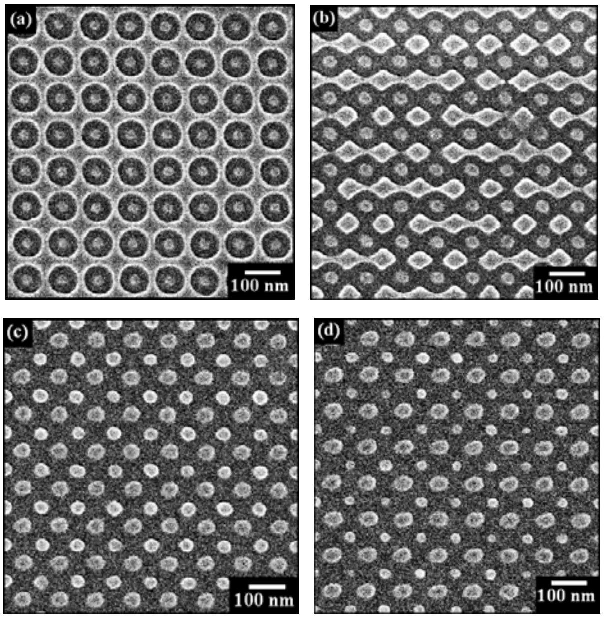

Fig. 1: SEM images of an initially 100 nm×100 nm pitch array of single pixel dots exposed with 1 keV electrons in an ~30 nm thick PMMA layer on a Si substrate, and developed at –15°C. The panels correspond to point doses of (a) 0.00666 pC (b) 0.0200 pC (c) 0.0300 pC (d) 0.0333 pC. (c) and (d) illustrate the density multiplication with a capacity of a control over features size by dose variation.

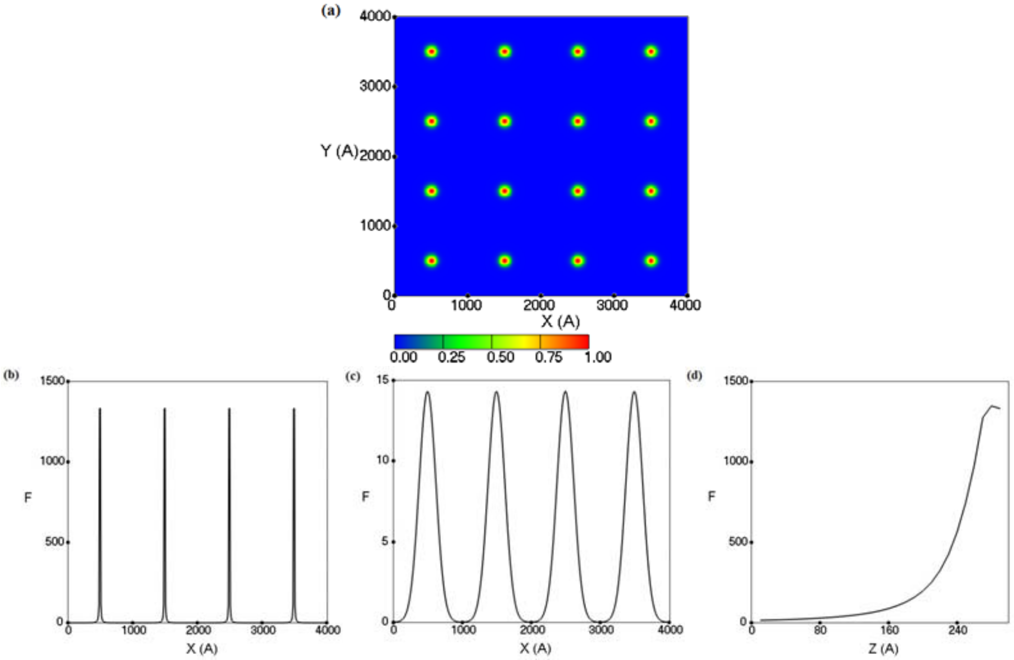

Fig. 2. The relative (normalized) lateral distributions of the yield of scissions per monomer (a), and the actual levels of the yield of scission at the top of PMMA (b), at the bottom (c), and as a function of the depth in an exposed spot (d) for the exposure conditions as in Fig. 1 (c). In (b) and (c), X is the lateral coordinate, and in (d), Z=0 corresponds to the bottom of the resist. The dimensions are in angstroms.