Large Area Three Dimensional Structure Fabrication using Multi-layer Electron Beam Lithography

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Three dimensional nanostructures are of great interest in photonics and sensor communities. Although there are many theoretical photonics models developed, lithographic reduction to practice is an ongoing challenge. Numerous lithographic techniques have been proposed for fabricating three dimensional structures with applications in photonics[1,2]. In this work, we describe a method that exploits intrinsic resolution and dose control of electron beam lithography systems combined with the penetration depth of high energy electron beams (>100keV) and tailored photoresist contrasts, tones. Photoresist materials have different sensitivities and tones, when combined with selective dose control can be exploited to fabricate three dimensional nanostructures.

Figure 1a and Figure 1b illustrate the process flow to fabricate three dimensional nanostructures in both positive and negative tone resists. This method has capability to fabricate a broad variety of nanostructures and for this work it was optimized to address the hierarchical nanostructures present on morpho butterfly scales[3]. Figure 1c, d show examples of two different multi-layer stacks where resist A, B are positive tone and resist X, Y are negative tone of different sensitivities. A top-down image of the CAD (computer aided design) file used for a 30-layer Copolymer/PMMA stack is shown in Figure 2a. The design file consists of two layers which are assigned different doses, where base dose X is 1500μC/cm^2 and 1X, 0.15X, 0X) represent assigned relative dose factors. Base dose refers to the dose required by the least sensitive layer in a given stack and dose values of other resist are normalized to base dose. Doses are assigned such that they address corresponding layers along penetration depth of the electron beam. 1X dose clears both PMMA and Copolymer layers (forms space between the structures), 0.15X clears only the Copolymer layer (forms lamellae) and 0X does not clear PMMA or Copolymer (forms ridges) on development. Figure 2c shows a cross-section SEM (Scanning Electron Microscope) image of the corresponding fabricated structure. Figure 2b shows a top-down image of another CAD design file with respective dose assignments (where X is 800 μC/cm^2) for fabricating 12-layer structures with supporting ribs for the lamella. Figure 2d shows cross-section SEM image of the fabricated structure.

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[2] C. Soukoulis, Martin Wegener, “Past achievements and future challenges in the development of three-dimensional photonic metamaterials”. Nature Photonics 5, 523-530 (2011)

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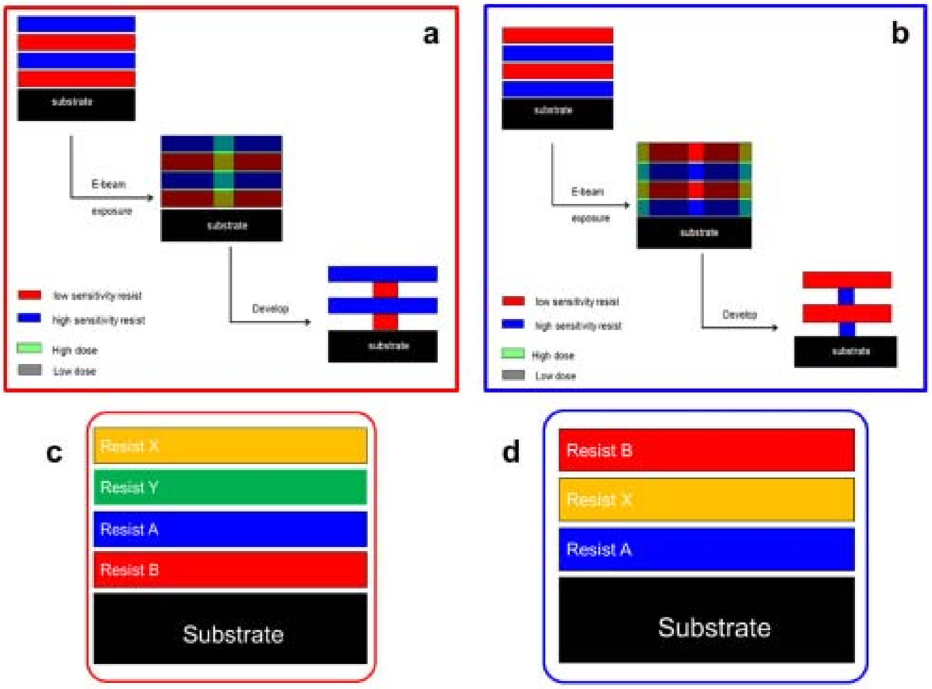

Figure 1

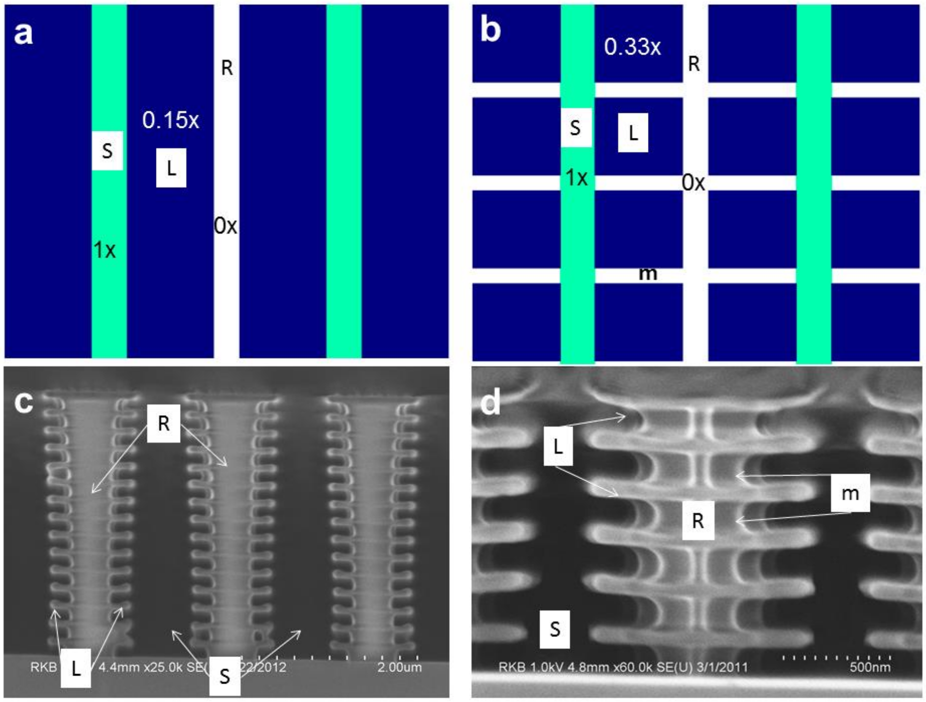

Figure 2