Maskless nanolithography approaches utilizing electron-beam-induced deposition

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Abstract

Electron beam-induced deposition (EBID) is a versatile direct-write deposition technique that can be used to deposit many materials with nanoscale precision. Recently electron-beam-induced deposition (EBID) has demonstrated ~ 1nm resolution[1]. Our group has studied both experimentally and via simulation the effects that different growth regimes have on EBID resolution. Nanoscale EBID deposits can be used to mask underlying materials from substrate processing, so that the direct-write material functions as a resist layer. In the case of post-EBID etching, the result is analogous to a negative tone resist scheme in which the exposed feature is protected from removal. In this paper we explored nanoscale electron beam induced deposited features as a dry development mask for photoresists which were subsequently used to anisotripically etch silicon nanostructures.

The purpose of this paper is to present results pertaining to the further development of EBID-based lithography techniques. A maskless, direct-write lithography (MDL) approach has been developed using electron beam-induced deposition to produce nanopatterns in the ~ 10 nm regime. Conceptual demonstration of the ideal process flow of EBID-based MDL is shown in Figure 1, which is a four-step process flow schematic of the negative tone process investigated in this work: Initially, ultra fine W patterns (dots and lines) were directly written onto a photoresist masking layer by EBID from $W(CO)_6$ precursor (Figure 1a); second, the EBID patterned resist was exposed to an oxygen plasma in order to “dry-develop” or remove the unprotected photoresist (Figure 1b); next, an anisotropic silicon reactive ion etching (RIE) recipe was developed to transfer the EBID pattern into the Si substrate (Figure 1c); and finally, the residual photoresist and W mask material were removed from the final silicon patterns through PR stripping (Figure 1d). Feature sizes as small as 13.5 nm were achieved through this approach (Figure 2). In this paper, we will briefly review the EBID lithography process and describe how various EBID parameters (dose, beam energy, precursor pressure, etc.) affect the process (resolution, and requisite exposure dose). We will also compare various EBID mask materials and discuss the relative benefits of each with respect to resolution, exposure dose, etch selectivity, and relative ease of fabrication.

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[1] W. F. van Dorp, B. van Someren, C. W. Hagen, P. Kruit, and P. A. Crozier, Nano Lett. **5,** 1303 (2005).

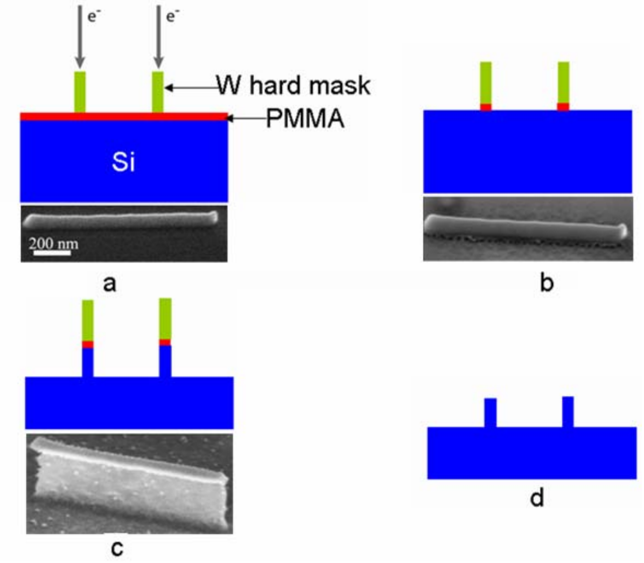

Fig 1: Process flow schematic for the EBID MDL technique. (a) EBID tungsten deposition on a resist-coated Si substrate; (b) The W masking layer is used to protect the underlying photoresist from an oxygen plasma dry develop; (c)The pattern is transferred to the substrate by reactive ion etching (RIE); (d) The masking layer can be removed by solvent stripping. Note: Corresponding SEM images (same magnification) were attached at the bottom of each schematic showing the actual results after each step.

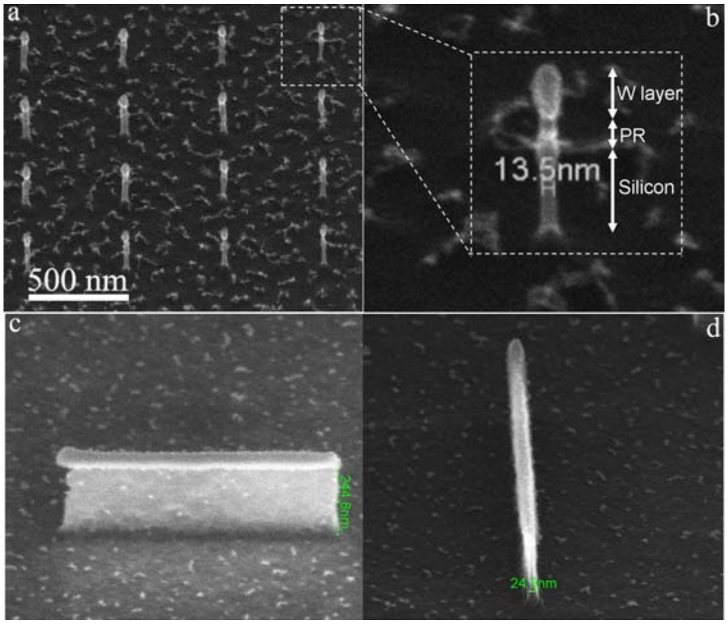

Fig 2: SEM images of post-develop/etch MDL experiments in which 2 keV e-beam energy and 21 pA current were used to deposit nanodots and nanolines. (a) EBID W nanodots pattern transferred to silicon nanopillars array; (b) High resolution image of one nanopillar, with a diameter of 13.5 nm. Residual photoresist and W mask can be seen on top of the Si pillar; (c) Pattern of EBID W nanoline transferred to ~ 250 nm tall thin wall of silicon; (d) Cross-section of the same pattern shown in (c), and the measured thickness of the pattern is 24.5 nm.