Out-of-plane nanofabrication using evaporated electron beam resist

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Conventional electron beam lithography (EBL) using spin-coated resist is a planar process. Previously, out-of-plane or 3D EBL has been realized using rotational stage or low-viscosity resist that can be coated on the sidewall of protruded ridges [1-2]. However, the coating is uniform only for ridges aligned with radial direction during spin coating. Here we show that out-of-plane EBL can be realized readily using resist evaporated onto high aspect ratio ridges (walls). The application for such structures can be numerous, such as 3D bowtie structure for light focusing.

Figure 1 shows the schematic fabrication process. First, high aspect ratio silicon walls were fabricated by EBL followed by non-switching or switching deep silicon etching using SF_6 and C_4F_8 gas, which has demonstrated ultra-high aspect ratio etching with smooth walls [3-7]. Similar structure can also be fabricated by conventional low temperature (sub-50°C) KOH etching of (110) wafer that could achieve aspect ratio of over 100 [8]. Onto this wall, polystyrene was then evaporated with the wafer tilted at an angle. Next, EBL was carried out with the wafer tilted, ideally close to 90 degree, to define the patterns on the wall. Finally the silicon wall can be etched through laterally using isotropic RIE with SF_6 gas, followed by polystyrene removal by oxygen plasma. Other materials such as gold can be coated onto the out-of-plane patterns to form, for example, 3D bowtie structure for light focusing.

As a proof of concept, we fabricated silicon nano-walls using EBL and deep silicon etching process, and coated 100 nm 1.2 kg/mol polystyrene on both sides of the wall at the wafer tilt angle of 45 degree. After EBL with the wafer tilted at 45 degree, the resist was developed by soaking in xylene for 1 min followed by rinsing with IPA. Then the silicon nano-walls were etched through with SF_6 gas (ICP power 50 W, 20V bias, 100 mTorr) that etches silicon and polystyrene at rate of 465 nm/min and 60 nm/min, respectively. Figure 2 shows the completed out-of-plane (as well as in-plane) nanostructures consisting of periodic ×-shaped patterns, which demonstrates the feasibility of the current process.

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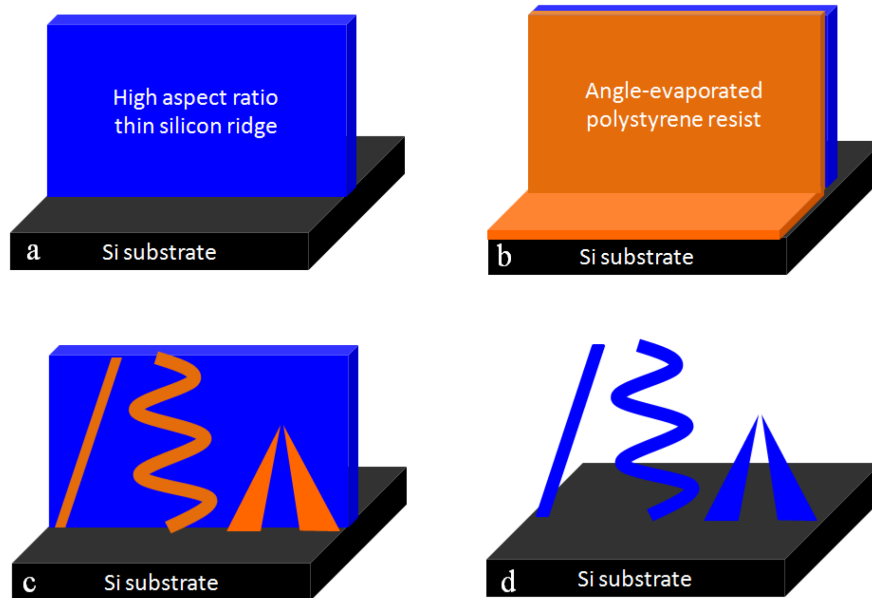

Figure 1. Schematic out-of-plane nanofabrication process. a) Fabricate high aspect ratio thin silicon nano-wall structure. b) Evaporate polystyrene resist with the wafer tilted at an angle, from one or both sides of the wall; c) Electron beam lithography with the wafer tilted at an angle to expose the resist on the wall; d) Etch through the silicon wall by isotropic RIE using SF_6 gas, and remove the remaining polystyrene by oxygen plasma. Here there structures are shown: tilted pillar, nano-spring and 3D bowtie.

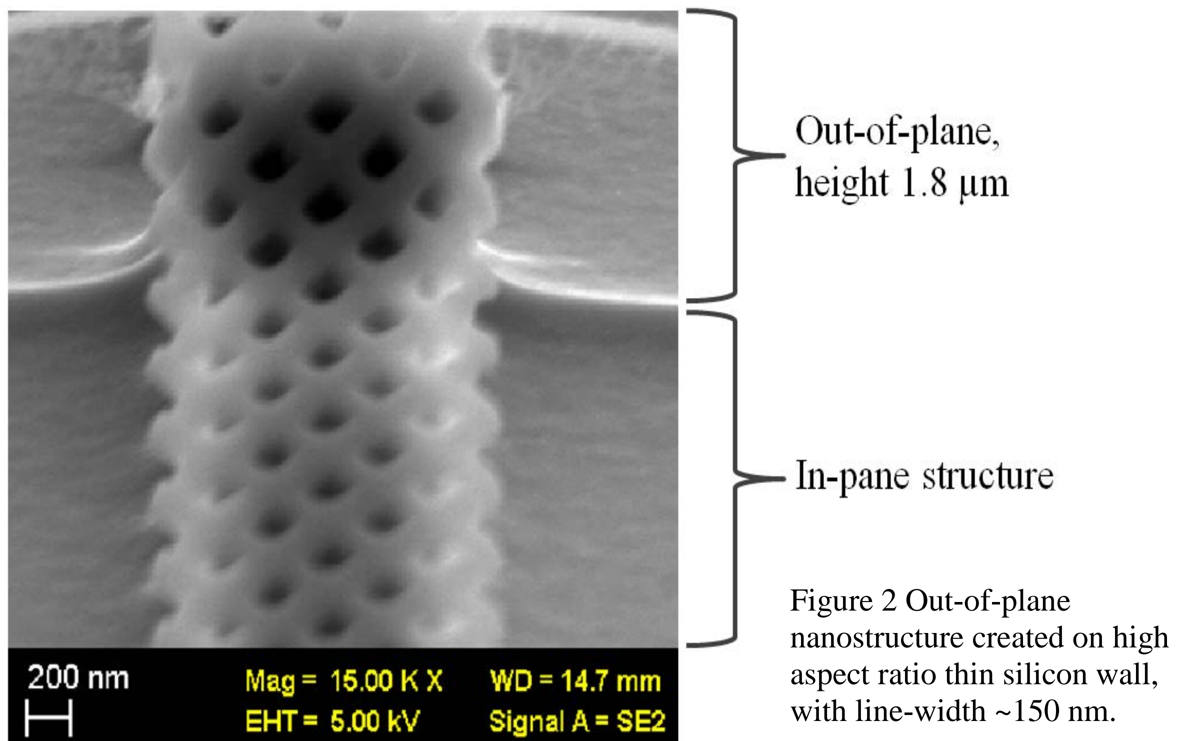

Figure 2 Out-of-plane nanostructure created on high aspect ratio thin silicon wall, with line-width ~150 nm.