Fabricating arbitrary silicon nanostructures using thermal dip pen nanolithography (tDPN)

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Thermal Dip Pen Nanolithography (tDPN) uses a heated atomic force microscope (AFM) tip to deposit molten polymer on a substrate, thus creating polymer nanopatterns.[1] tDPN can write polymer nanowires from many different polymers, including polystyrene (PS).[2] Here, we demonstrate that tDPN-fabricated polymer nanostructures can further serve as etching masks for fabricating silicon and silicon oxide structures. This paves an important step for using tip-based nanofabrication to fabricate solid state devices. We show the flexibility of the technique by demonstrating the fabrication of arbitrary solid structures of silicon oxide such as straight fin array, dot array, curved fin array, ring, oracle characters and lotus flower. Moreover, we combine tDPN with metal-assisted chemical etching (MacEtch) and fabricated aligned vertical silicon nanowire array.

Figure 1 shows the process to fabricate arbitrary silicon oxide structures using tDPN. First, we grew 50 nm thick silicon oxide by thermal oxidation. Then a heated AFM tip deposited the PS nanopatterns. After an annealing step to increase the adhesion between PS and silicon oxide, buffered hydrofluoric acid etched the silicon oxide not protected by PS nanopatterns. Finally, we removed the PS nanopatterns via oxygen plasma etching. Figure 2 shows the SEM images of various patterns of silicon oxide. Figure 3 shows the process of fabricating aligned vertical high-aspect-ratio silicon nanowires (Si NWs) using tDPN and MacEtch. First, a heated AFM tip created PS nanopatterns via tDPN. We then etched silicon via the Bosch process to create a shallow silicon structure having a profile amenable to Au lift-off. Then we evaporated a 35 nm thick Au layer onto the sample. The Au layers on the top and the bottom of the silicon nanostructure were separated due to the vertical sidewalls. Finally, we dipped the sample into MacEtch solutions (1:2:2 volume ratio of 5.75 M hydrofluoric acid, 3.88 M hydrogen peroxide and 6.86 M ethanol) to produce vertical Si NWs with smooth sidewalls. Figure 4 shows the SEM images of vertical Si NWs. Figure 4 shows the Si NWs separated by distances of 1.5, 2, and 1 µm.

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[1] P. E. Sheehan, L. J. Whitman, W. P. King, and B. A. Nelson, Appl Phys Lett **85** (9), 1589(2004)
[2] W. K. Lee, Z. T. Dai, W. P. King, and P. E. Sheehan, Nano Lett **10** (1), 129 (2010)

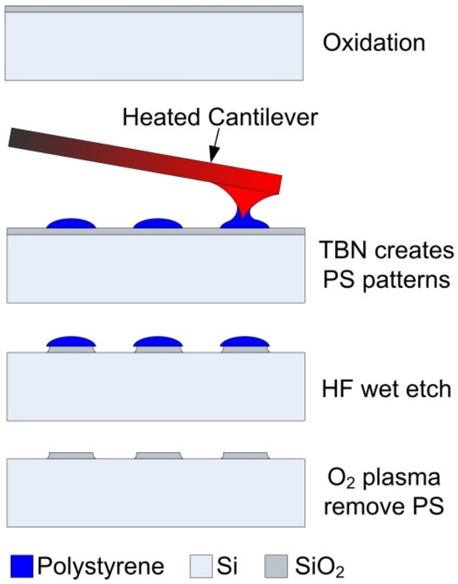

Figure 1: A schematic drawing depicting the fabrication process of silicon oxide nanostructures using tDPN.

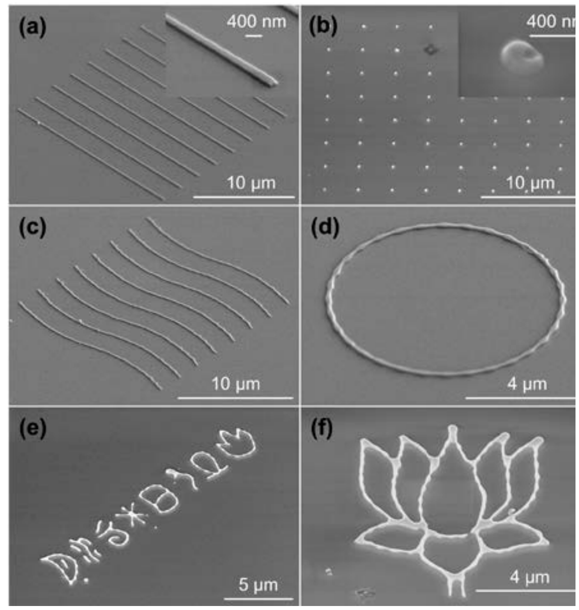

Figure 2: SEM images of various silicon oxide nanopatterns fabricated by tDPN. All the nanopatterns are 50 nm in height.

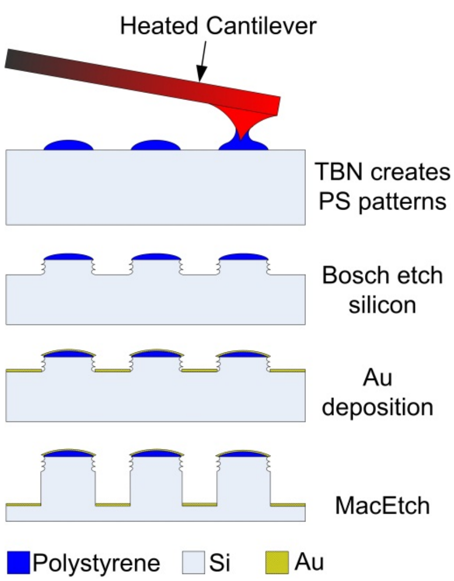

Figure 3: A schematic drawing depicting the fabrication process of vertical silicon nanowires using tDPN and MacEtch.

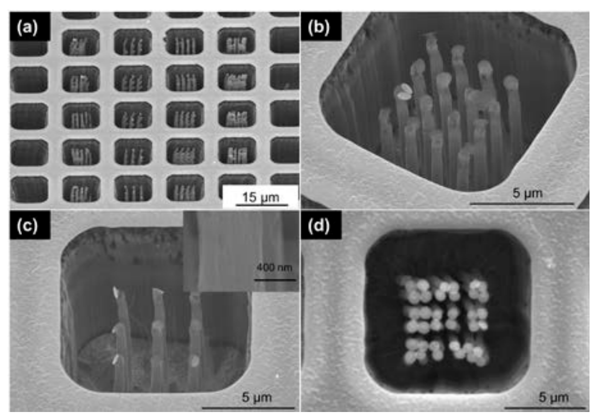

Figure 4: SEM images of vertical silicon nanowires (Si NWs) fabricated using tDPN and MacEtch: (a) an overview of 20 array of vertical Si NWs; (b) a 4×4 array of Si NWs with 1.5 μm spacing; (c) a 3×3 array of Si NWs with 2 μm spacing; (d) a 6×6 array of Si NWs with 1 μm spacing. All the Si NWs are 500 nm in diameter and 8 μm in height.