Fabrication and Characterization of Vertical Silicon Nanopillar Schottky Diodes

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Introduction:
Schottky (rectifying metal-semiconductor) contacts have widespread use, particularly in high frequency [1] and high power electronic devices [2]. It is important that Schottky diodes be miniaturized to preserve their functionality as devices shrink to the nanoscale [3], for applications such as voltage clamping, rectification in switched-mode power supplies, and reverse current protection in photovoltaic systems [4]. Standing upright, nanopillars can access vertical dimension in device fabrication, which is recognized as an important step in maintaining and/or surpassing Moore’s law [5]. Here, we present a low temperature (no thermal oxide required), top-down process for fabricating arrays of vertical n-type silicon nanopillar Schottky diodes that can be incorporated into planar complementary metal oxide semiconductor (CMOS)-integrated circuits. We also characterize our metal-semiconductor (nickel-silicon) contacts and note that they differ from planar diodes.

Experimental Procedure:
A schematic representation of the fabrication process is shown in Figure 1. First, a hard mask of square-shaped SiO2 islands (side lengths of 40 to 100 nm) was formed in arrays with a 4 µm pitch on an n-type (~ 2 × 10¹⁵ cm⁻³) silicon (Si) substrate. This was done using electron beam lithography to expose arrays on a spin-coated 200 nm thick layer of 950K poly(methyl methacrylate) (PMMA). After developing the pattern at room temperature, roughly 50 nm of SiO2 was deposited with electron-beam evaporation. The excess resist was dissolved in acetone, lifting off the oxide layer except for the SiO2 islands.

Figure 1: Schematic representation of fabrication process (not to scale).

Figure 2: (a) SEM image of a 500 nm pitch array of 100 nm nanopillars after Bosch process using 4 sec etch, 2.5 sec deposition cycle. (b) Close-up of a 100 nm nanopillar in (a). (c) 4-micron pitch array of 100 nm diameter nanopillars obtained from using 8 sec etch, 5 sec deposition cycle. (d)-(g) Single nanopillars sized 40 nm, 60 nm, 80 nm, and 100 nm processed as in (c).

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An unexpected outcome that differentiates these diodes from planar diodes was non-ideal current scaling with respect to both number of diodes and radius. For the former, a linear relation was expected since the diodes are probed in parallel, but not observed: current ratios between the 40, 160, 240 to the 400 pillar array were roughly 1%, 10%, and 15%, respectively, compared to the expected 10%, 40%, and 60%. For the latter, dependence on area (radius squared) was expected because the heights of the nanopillars are consistent, but the power was found to be about 1.2 instead of 2. This indicates a dependence on perimeter size, and hence the increased importance of surface states due to a higher surface area to volume ratio.

Future Work:
Further research is needed to minimize scalloping to optimize nanopillar quality. The main parameter to be altered in this work should be the etch rate, in order to minimize the isotropy of the etching mode. Additionally, the non-ideal current scaling must be researched to be fully understood. One theory to account for this with respect to number of diodes is that a combination of inconsistent numbers of unintended “stray” nanopillars and faulty nanopillars are contacted with nickel, varying the actual amount probed from the assumed. Electron beam induced current (EBIC) is a method that could test this theory by illuminating the functioning diodes.

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References: