Sub-10 nm Fabrication of Large Area Periodic Nanopillars

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Abstract

Here we present a large-area fabrication technique that is capable of producing size-tunable periodic silicon nanopillar arrays with sub-10 nm resolution. Our approach is to transfer the patterns created by nanosphere lithography into silicon substrates, forming nanopillar arrays and modify the size, shape and height of nanopillar arrays by various etching schemes.

Introduction

To construct nanostructures with high degree of control, electron beam lithography is the most commonly used technique. However, the generation of secondary electrons during electron bombardment makes it difficult to pattern with sub-10-nm resolution[1]. It is also inefficient to employ electron beam lithography for large-areas production because it is a sequential patterning technique. Scanning probe based lithographic techniques[2-4] has also been used to pattern nanostructures with very high degree of control. However, it is very time consuming for scanning probe based lithography to create large area patterns at the nanometer scale. It has been reported recently that large-area periodic nanostructures can be obtained by transferring the patterns formed by the self-assembled nanospheres into silicon substrates forming nanopillar arrays and replicating the nanostructures using nanoimprint lithography[5]. Since the size of silicon nanopillars can be trimmed by oxidation and etching processes, this approach provides an excellent way to produce size controllable nanostructures. In this paper, we report a simple fabrication process for producing large-area, size-tunable, periodic nanopillar arrays with lateral resolution smaller than 10 nm.

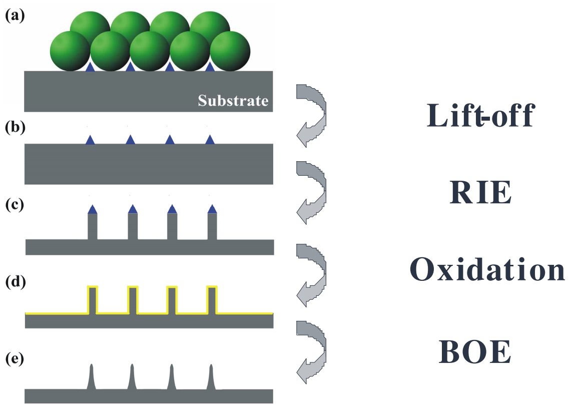

Figure 1. Scheme for the fabrication of size-tunable periodic silicon nanopillar arrays.

Experimental

Figure 1 illustrates the procedure for producing large-area nanopillar array with sub-10 nm resolution. To fabricate silicon nanopillar, silicon substrates are first coated with monodispersed polystyrene solution to form large-area close packed structures on the surfaces. Depending on the concentration and the speed of the spin-coater, single-layer or double-layer polystyrene template can be created. Since the double-layer template produces periodic structures that are more suitable for commercial applications (fig 1a), we will focus our discussion on the features created by the double-layer templates. In the second step, a thin chromium film is deposited on the double layer template and the polystyrene beads can be dissolved in CH_2Cl_2 solution leaving periodic metal arrays on the surface (fig 1b). These periodic metal arrays then serve as the etching masks in the reactive ion etching process. By placing the silicon substrates in a reactive ion etcher, large-area silicon nanopillar arrays can be obtained (fig. 1c). After removing the chromium nanoparticles in chromium etchant, the substrate is placed in an oven purged with pure oxygen to form a layer of silicon oxide on the surfaces of nanopillars (fig. 1d). The thickness of the oxide layer can be precisely controlled by the oxidation time. After removing the oxide in oxide etching solution, silicon nanopillars with smaller lateral dimension can be obtained (as shown in fig. 1e). Using this approach it is possible to systematically reduce the size of nanopillars to the sub-10 nm regime.

Results

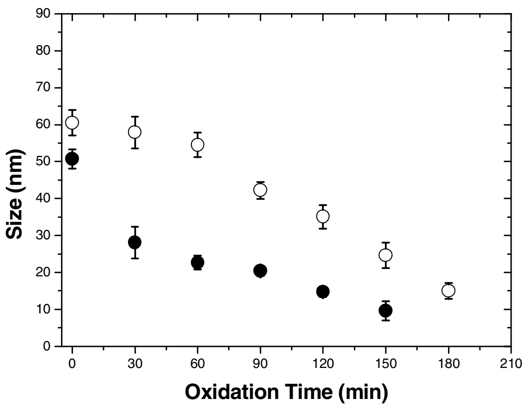

Figure 2. The relationship between the lateral dimension of nanopillars and the oxidation time. The filled circles are nanopillars fabricated by 280 nm double-layer templates, and the open circles are nanopillars formed on 440 nm double-layer templates.

We have systematically fabricated periodic silicon nanopillars with different lateral dimensions using two different templates, 280 nm and 440 nm diameter double-layer polystyrene templates. The measured lateral dimensions of silicon nanopillars are plotted as a function of the oxidation time in figure 2. To obtain sub-10 nm silicon

nanopillars, longer oxidation time were used. Shown in figure 3 are silicon nanopillar fabricated using both 280 nm and 440 nm diameter polystyrene templates and the oxidation time was 150 min.

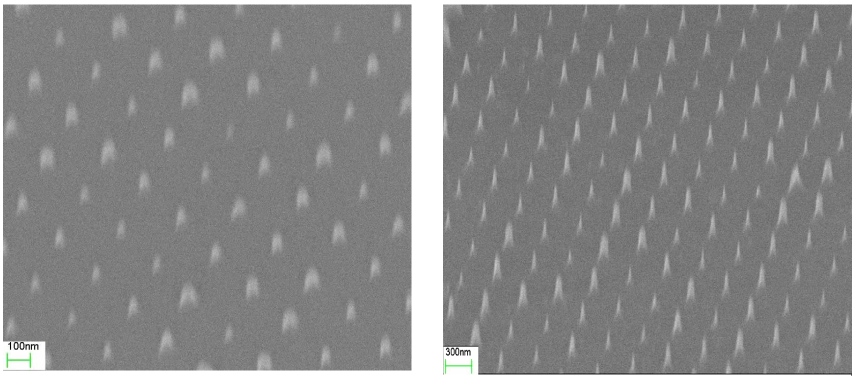

Figure 3. SEM images of sub-10 nm nanopillar arrays fabricated by 280 nm double-layer (left) and 440 nm double-layer (right) templates..

Conclusion

In summary, we have fabricated large-area, well-order periodic nanopillar arrays with feature size less than 10 nm and the area covered with nanopillars is larger than $1cm^2$. The lateral dimension of silicon nanopillars can be systematically reduced from ~60 nm down to sub-10 nm region by adjusting the oxidation time. And the periodicity of nanopillar arrays can be adjusted by selecting the size of polystyrene beads.

Acknowledgement

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