Effect of Pillar Geometry on Mechanical Properties and Antireflection Effects of Silicon Nanostructures

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Many species in nature utilize nanostructures for various functions such as antireflection and self-cleaning. These properties have been studied intensively and have led to novel engineered materials with superior optical, surface and mechanical properties. Broadband antireflection and absorption are achieved through high aspect ratio nanopillars with sub-wavelength feature sizes [1]. Arrays made of high aspect ratio and dense nanopillars are also used to generate self-cleaning superhydrophobic or wicking surfaces [2]. However, there is limited research on the mechanical behavior of surfaces with different nanostructure geometries. In previous work, we investigated the mechanical properties of nanostructured surfaces using nanoindentation [3]. However, the trade-off between structure geometry vs mechanical and optical properties is not well-understood. To utilize these structures in areas such as solar panels and smartphone displays, their mechanical robustness should be further investigated to design more robust structures to ensure extended use. Moreover, it is important to further investigate the effect of nanopillar geometry on mechanical properties of nanostructured surfaces, including stiffness, hardness, and modulus.

In this work, we examine the effect of pillar geometry on mechanical behavior and antireflection effects of silicon nanopillars with 300 nm period and different pillar height, slenderness ratio and shape. The nanopillar arrays are patterned using a Lloyd's mirror interferometer and transferred to the underlying substrate using reactive ion etching, as illustrated in Fig. 1a. The cross-section scanning electron microscopy images of nanopillars in Fig. 1b and Fig. 1c show the structure geometry variation of nanopillars with 500 nm and 1 μm height, respectively. The antireflection effects will be examined via spectrophotometry. The proposed mechanical characterization methods are nanoindentation to measure hardness and modulus at different indentation depth, and pencil hardness testing to show the mechanical robustness of the surfaces. Quasi-static and cyclic nanoindentation test methods will be utilized with a conospherical indenter with an indenter tip radius of 10 μm. The effect of pillar geometry on antireflection, hardness, modulus, fracture behavior, and mechanical robustness of the nanostructured surfaces will be investigated.

Preliminary cyclic nanoindentation measurement results, given in Fig. 2, show that both samples have three different deformation regimes. The first regime is elastic deformation, the second is large deformation at an intermediate load and the last one is the densification of the structure. Low aspect ratio nanopillar sample has smaller hysteresis between each unloading and loading segments as illustrated in Fig. 2a. Moreover, Fig. 2b shows high aspect ratio nanopillar sample has more pop-ins before the densification due to buckling of the pillars before breaking upon successive loading. On the other hand, low aspect ratio silicon nanopillars fractures directly without buckling. The hardness of low aspect ratio nanopillar sample is two orders of magnitude higher than that of high aspect ratio nanopillar sample. We will present the fabrication details, mechanical and optical test results. This work will reveal the trade-off between mechanical robustness and antireflection effects of these materials. The findings will help design and fabrication of mechanically durable nanostructured surfaces for various applications in multifunctional surfaces, nanophotonics, and renewable energy areas.

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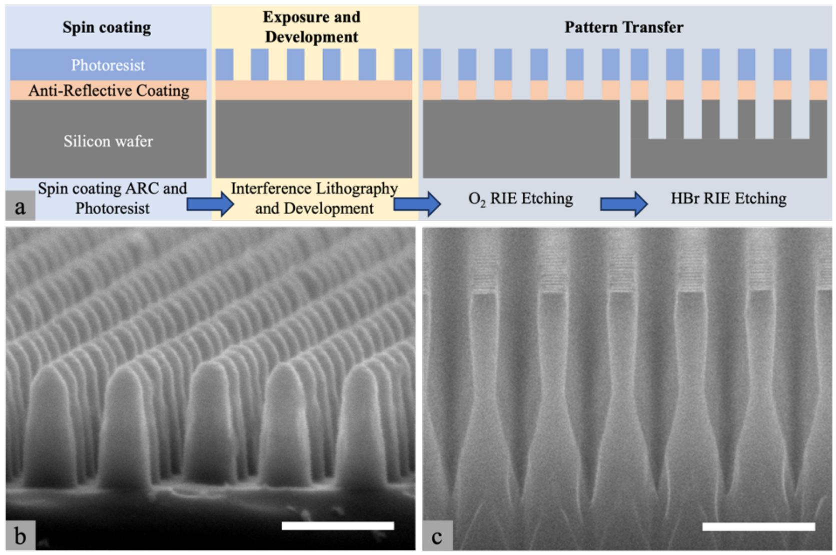

Figure 1: **(a)** Schematic illustration for the nanostructure fabrication process. Cross-section SEM image of the **(b)** low, and **(c)** high aspect ratio silicon nanopillar structures. Scale bars: 500 nm.

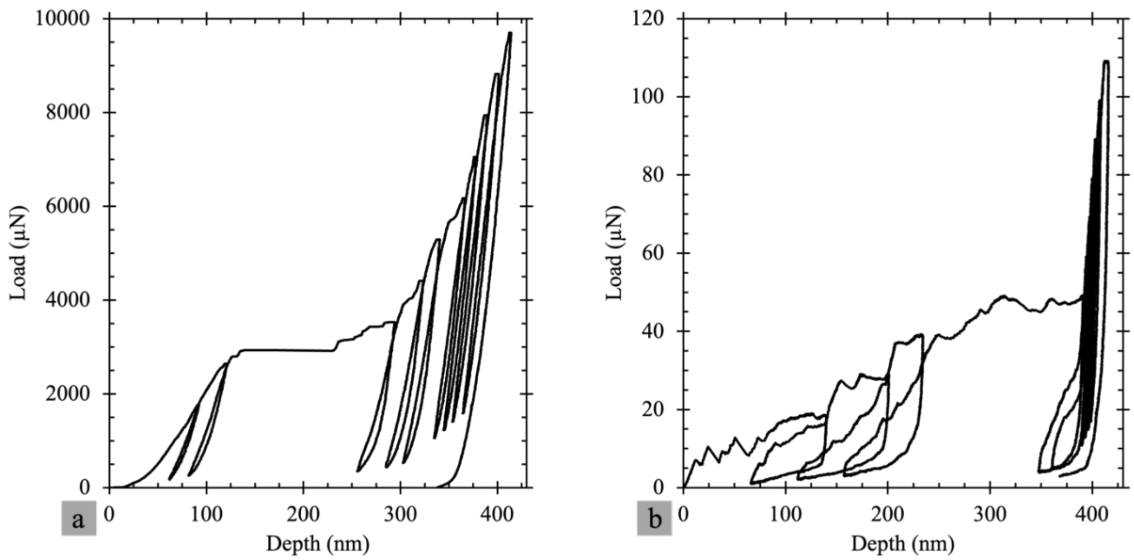

Figure 2: Cyclic nanoindentation load-depth graphs for **(a)** low, and **(b)** high aspect ratio nanopillars.

References

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