Mechanical Testing of Silicon and Sapphire Nanopillar Structures

Mehmet Kepenekci, Kun-Chieh Chien, Chih-Hao Chang
Walker Department of Mechanical Engineering, The University of Texas at Austin, Austin, TX 78712, USA
mehmetkepenekci@utexas.edu

Nanostructures and nanostructured materials have remarkable properties and are used in a wide range of applications in displays, photonics, and renewable energy. By fine tuning the geometry of the structure, they can enhance the optical transmission of an optical surface by reducing Fresnel reflection losses and create self-cleaning and water repellent surfaces [1]. While the optical and wetting properties of surface nanostructures have been investigated for several decades, the mechanical properties of these structures are not very well understood. As a result, there are lingering questions regarding the mechanical durability and wear of these nanostructures, especially for long-term applications such as solar panels and touch-screen electronic display. Therefore, the mechanical characterization of nanostructured materials and properties such as stiffness, strength, and hardness need to be further investigated.

In this work, we examine the mechanical properties of periodic silicon and sapphire nanopillars using nanoindentation. The high aspect-ratio silicon structures are patterned in photoresist using interference lithography and then pattern transferred to the underlying substrates reactive ion etching (RIE) processes [2], as illustrated in the schematic shown in Fig. 1(a). The cross-section scanning electron microscope (SEM) images of silicon nanopillars with 300 nm period and 1 µm height is shown in Fig. 1(b). The proposed mechanical characterization technique will be based on nanoindentation, which can measure mechanical properties in the realm of tens of nanometers of indentation depth [3]. The mechanical response of the nanopillars will be examined using quasi-static and cyclic nanoindentation with a conospherical indenter with a tip radius of 10 µm. The effect of the structure geometry, material properties and the depth dependence on the mechanical properties will be investigated.

Preliminary measurement of the indentation load vs depth is shown in Fig. 2. Here it can be observed that the silicon nanostructures exhibit a three distinct deformation regime, which includes local strain of the structure at low depth. The pillars then bend at intermediate load, leading to large strain and a ductile-like response. At high indentation depth densification of the structure can be observed, leading to higher stiffness and slope of the load vs displacement curve. The corresponding behavior of the structure can be observed in the inset SEMs. On the other hand, the deformation of the sapphire pillars has high hardness and elastic modulus despite the relative low density of the structure. The test results show that there is an improvement in ductility due to the nanostructure as force and displacement graphs did not exhibit an explicit pop-in region. The second regime is also not readily observed, showing lower structure-induced ductility in the mechanical response. We will present detailed fabrication and nanoindentation results on the depth-dependent stiffness, hardness, and strength of the silicon and sapphire nanostructures. This work will also shed light on how these two materials behave at the nanoscale, hence, will help to identify the similarities and differences. The findings will help guide the design and fabrication of mechanically robust nanostructured materials with fine-tuned surface properties for applications in nanophotonics, multifunctional surfaces, and display.

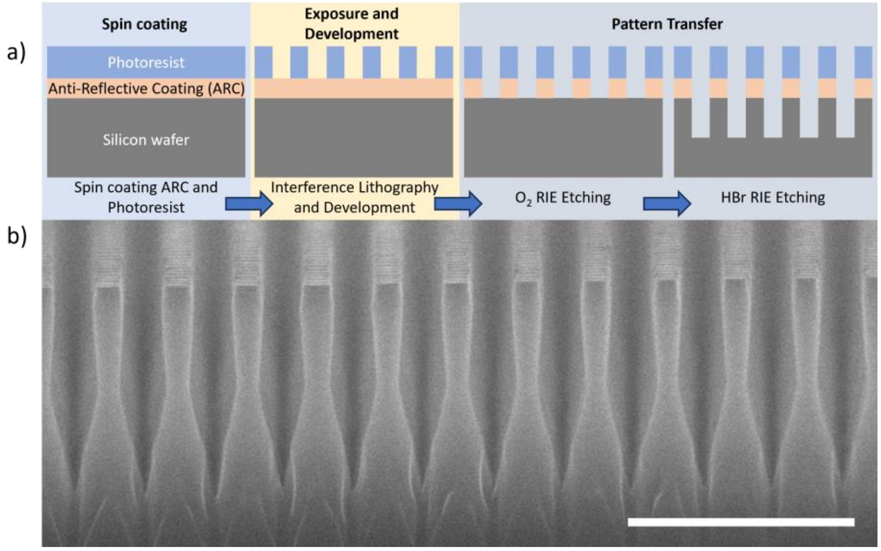

Figure 1: (a) Schematic illustration for the nanostructure fabrication process. (b) Cross-section SEM image of the silicon micropillar structure to be tested. Scale bar: 1 µm.

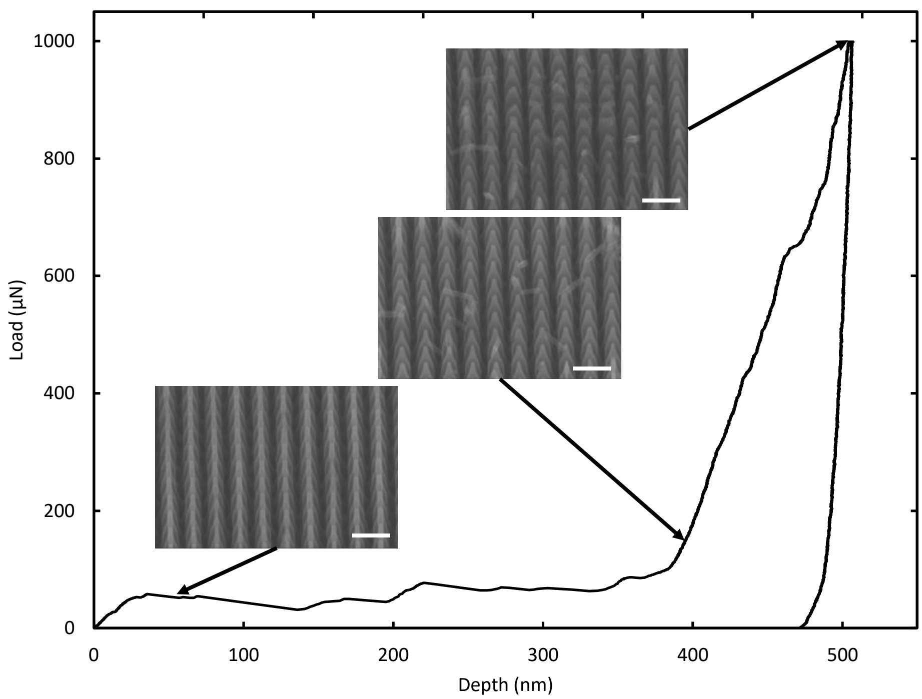

Figure 2: A force-displacement graph of nanoindentation on the surface of a nanostructured silicon sample. Inset images are structure after testing. Scale bars: 500 nm.

References

[1] K.-C. Park, H. J. Choi, C.-H. Chang, R. E. Cohen, G. H. McKinley, and G. Barbastathis, ACS Nano **6**, 3789 (2012).

[2] K.-C. Chien and C.-H. Chang, Journal of Vacuum Science & Technology B **40**, 062802 (2022).

[3] W. C. Oliver and G. M. Pharr, J. Mater. Res. **19**, 3 (2004).