Mechanically robust antireflection sapphire surfaces via nanopillar arrays

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Fresnel reflection losses from surfaces has been one of the primary problems in optical devices that has been solved through various methods. Quarter-wavelength and multilayer antireflection coatings have been the industry standard to reducing these losses. However, these methods require multilayer coating and can suffer from delamination. On the other hand, moth-eye structures offer antireflection with enhanced omnidirectional optical transmission without a need for coating.[1] This is achieved through matching the index of air gradually via the nanopillar arrays on the surface. It is also shown that these nanostructured surfaces also offer dust mitigation, self-cleaning, and anti-fogging properties.[2,3] In previous work, we examined the mechanical and optical properties of silicon and sapphire nanopillars.[4,5] However, the tradeoff between the two properties is not well understood and more insights are needed to engineer mechanically robust antireflection nanostructures.

This works investigates the optical and mechanical properties of sapphire nanopillar arrays to investigate the balance between the antireflection and scratch-resistance. The fabrication process steps are summarized in Fig. 1a. Polysilicon mask is deposited on sapphire substrates via low-pressure chemical vapor deposition (LPCVD) to enhance the etch depth. Then antireflection coating and photoresist layers are spin coated. The nanopillar array is patterned through Lloyd's mirror interference lithography via double exposure. The development and inductively coupled plasma - reactive ion etching (ICP-RIE) steps are followed by KOH etching to remove the remaining polysilicon to obtain the sapphire nanopillars shown in the cross-section SEM image in Fig. 1b and AFM image in Fig. 1c. The mechanical properties of the samples are measured using Hysitron TI-950 Triboindenter via quasi-static and cyclic nanoindentation methods with a conospherical indenter with 10 µm tip radius. The optical reflection and transmission properties of the samples are measured through a Cary 5000 UV-Vis-NIR spectrophotometer.

The initial nanoindentation results shows both samples have high hardness and modulus values, comparable to scratch-resistant metals and soda-lime glass. The preliminary results show the maximum hardness of tall and short structures are 3.7±0.7 GPa and 8.4±0.4 GPa, respectively. The indentation modulus values are 172.6±8.4 GPa and 199.9±5.1 GPa for tall and short nanopillar structures, respectively. The load-depth graph at a similar maximum load shown in Fig. 2a further shows that the shorter nanopillars are more mechanically robust. The optical transmission measurements in Fig. 2b show a similar trend in maximum transmittance between 350 nm to 750 nm wavelength. However, shorter structures with smaller nanopillar array period exhibits better performance at shorter wavelength. Therefore, there is a significant hardness enhancement while offering better transmittance within the wavelength limits thanks to the antireflection effect of moth-eye structures. Nanopillar arrays with smaller period and height could further enhance the mechanical properties while keeping antireflection effects. This work will reveal the trade-off between mechanical robustness and antireflection effects and will help enable mechanically durable nanostructured surfaces for applications in multifunctional surfaces, nanophotonics, and renewable energy. We will present the fabrication details, mechanical and optical test results.

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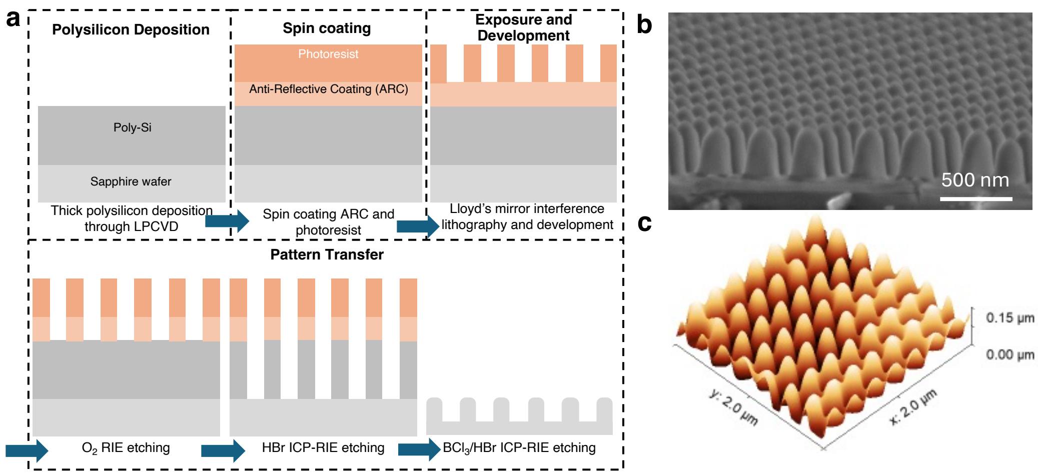

Figure 1: **(a)** Schematic illustration for the sapphire nanopillar array fabrication process. **(a)** Cross-section SEM image of the long and, **(c)** AFM image of the short sapphire nanopillars.

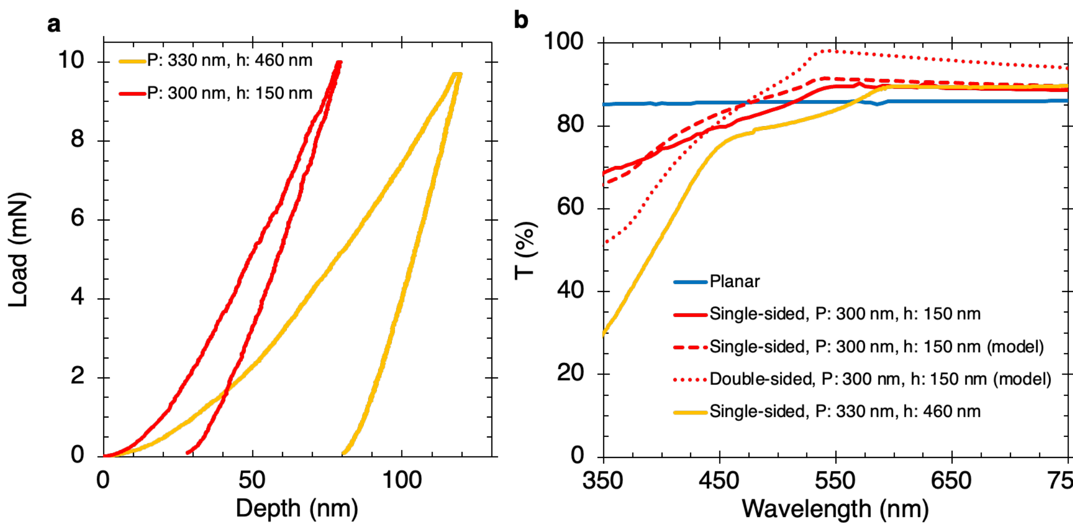

Figure 2: **(a)** Load-depth nanoindentation graphs of quasi-static nanoindentation test of short and tall sapphire nanopillars. **(b)** Optical transmission measurement of planar and nanostructured sapphire samples, and RCWA models of single- and double-sided short sapphire structures.

References

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