Soft and hard trimming techniques of imprint resists to fabricate silicon nanodisk arrays with different circularity

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Resist trimming technique is one of the methods for nanopatterning beyond resolution limit of respective lithography technologies. Structural colors of silicon nanopillar arrays have been successfully tuned by UV nanoimprint lithography using resist masks trimmed by oxygen reactive ion etching (O_2 RIE).[1] However, the vulnerable resist property for O_2 RIE causes silicon nanopillars with large edge roughness. For cases of TiO_2 metasurfaces,[2] the theoretical simulation indicates that the side-wall roughness can be considered as an optical loss layer which influences optical resonant modes. Therefore, precise control of edge and side wall roughness is necessary to understand optical properties of metasurfaces. In this study, we compare soft trimming by UV/O_3 and hard trimming by O_2 RIE to control the shapes of imprint resist masks and silicon nanodisks.

A dye-containing UV-curable liquid (BGBE127)[3] was used, and its spin-coated film on a Si substrate was imprinted with a mold having a hole diameter of 350 nm as described previously.[4] Residual layers of imprint resin patterns were removed using a custom-made O_2 RIE instrument.[5] Then, soft trimming was performed using a UV/O_3 cleaner, whereas hard trimming was performed with the O_2 RIE instrument. The whole procedures to fabricate silicon nanodisk arrays are shown in Fig. 1. To evaluate the edge roughness of resist masks after O_2 RIE and silicon nanodisks after ICP dry etching, the circularity was measured from FE-SEM images by binarization using software.

The hard trimming caused 10 nm-width wrinkled resist masks (Fig. 2a), whereas the soft trimming resulted in smooth resist masks (Fig. 2b). The generation of the wrinkled structures was attributable to the process of O_2 RIE. The imprint resist made with BGBE127 had a transferring property with a width of 10 nm through ICP dry etching. Figure 3 shows the tilted and top-view FE-SEM images of silicon nanodisk arrays via hard trimming (Fig. 3a) and soft trimming (Fig. 3b). The silicon nanodisks with a height of 170 nm had walls perpendicular to the substrate surface. The wrinkled structure of the resist shape was transferred to the side walls of silicon nanodisks. We separately fabricated wrinkled silicon nanodisk arrays (diameter, 250 nm; circularity, 0.87) and smooth silicon nanodisk arrays (diameter, 200 nm; circularity, 0.90). In summary, we successfully controlled the resist edge roughness and silicon side-wall roughness by choosing the soft and hard trimming procedures.

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[1] X. Cao et al., *Adv. Photonics Res.* **3**, 2200127 (2022)
[2] H. Yang, et al., *Nanophotonics* **9**, 1401 (2020)
[3] M. Nakagawa et al., *Jpn. J. Appl. Phys.* **62**, SG1010 (2023)
[4] C. Miyajima, et al., *J. Vac. Sci. Technol. B* **39**, 052804 (2021)
[5] T. Uehara, et al., *J. Photopolym. Sci. Technol.* **29**, 201 (2016)

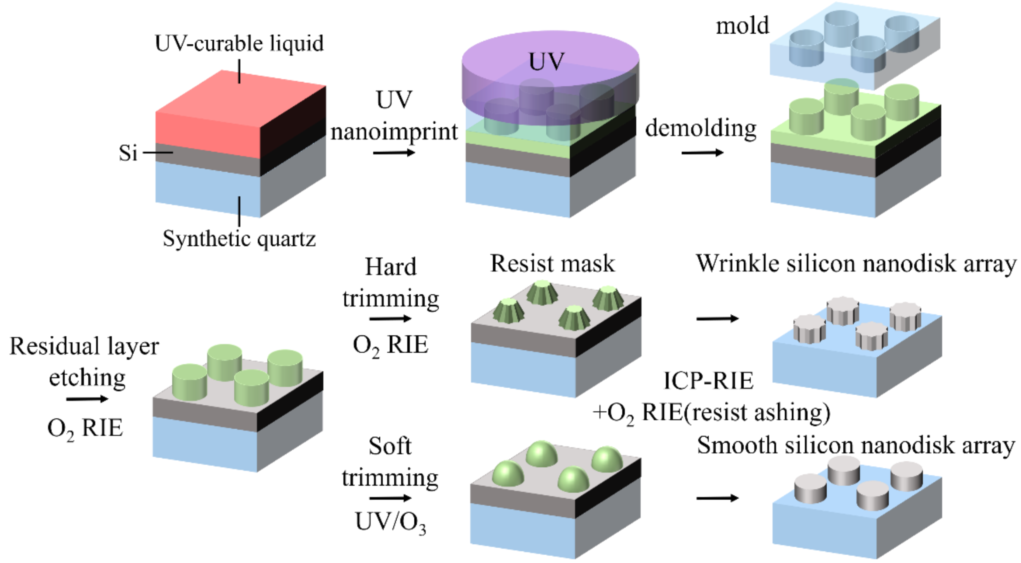

Figure 1: Schematic illustrations of procedures to fabricate wrinkled and smooth silicon nanodisk arrays achieved by hard trimming O_2 RIE or soft trimming UV/O_3.

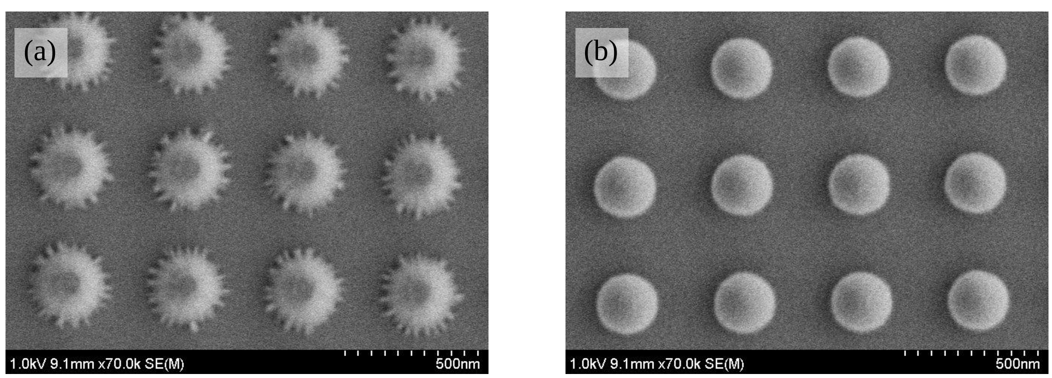

Figure 2: FE-SEM images of imprint resist masks (a) after hard trimming (O_2 RIE) under the condition of O_2 flow rate of 4.0 sccm, pressure of 0.2 Pa, RF power of 30 W and (b) after soft trimming (UV/O_3).

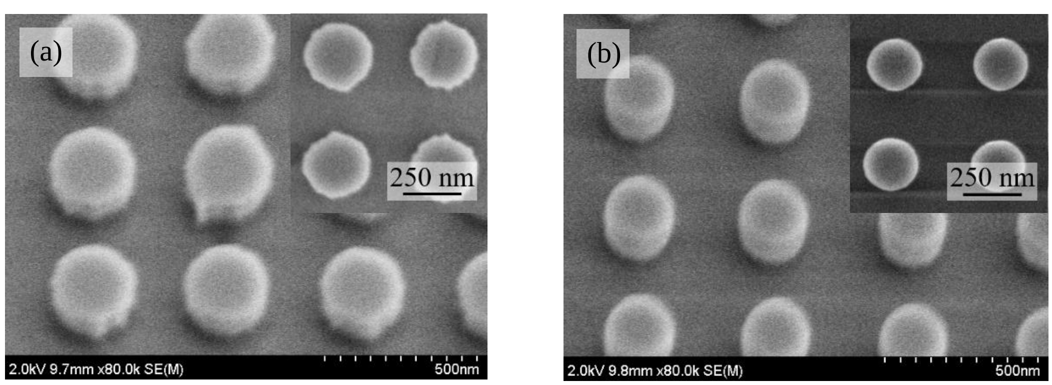

Figure 3: Tilted- and top-view FE-SEM images of (a) wrinkled silicon nanodisk array prepared via hard trimming and (b) smooth silicon nanodisk array prepared via soft trimming.