Electronic Supplementary Material (ESI) for Soft Matter

Supplementary Information for Micro Lens-on-lens Array

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1. Experimental

Convex MLA fabrication

A silicon wafer template (20x20 mm^2) with cylindrical pores (d_{MLA}/l_{MLA}=2/3, 10/15, 100/150 μm) in a square pattern was placed on the heating stage inside a vacuum chamber. After the PC film (30x30 mm^2, 250 μm thick) was placed on the template, PC was pressed against the template with a 500g metal weight. The pressure inside the vacuum chamber was then lowered to P_{in} (~0.001, 0.16, 0.32, 0.51, 0.65 atm) and the temperature of PC was increased to approximately 160℃, which is ~7℃ above the glass transition temperature of PC (T_g=153℃). The entire set was maintained at that temperature for 2 min. to allow the molten PC to seal the CMCs in the template. The vacuum was then released to induce a pressure difference between the outside and inside CMC ($\Delta P = (P_{out}-P_{in})$=1.0, 0.84, 0.68, 0.49, 0.35 atm, respectively) and allow the molten polymer to flow into the CMC for three minutes.($P_{in}<P_{out}$) The entire set (template and PC film) was quenched into the cold water to freeze the flow of PC. The final convex MLA could be obtained upon mechanical separation of the PC film from the template.

Concave MLA fabrication

While the vacuum chamber was maintained at atmospheric pressure (P_{in}=1atm), the PC film on top of the template was heated to 160℃ and was maintained at that temperature for 2 min. to seal the CMC with the molten PC. The pressure of the vacuum chamber was then lowered to P_{out} (~0.001, 0.14, 0.30, 0.54, 0.68 atm) to induce a pressure difference ($\Delta P=P_{in}-P_{out}$= 1.0, 0.86, 0.70, 0.46, 0.32 atm, respectively) and the entire set (PC and template) was kept under this condition for 3 min. to allow the molten PC to flow out to form a concave shape. After venting the chamber quickly, the template and PC film were quenched and separated mechanically.

MLLA fabrication

A silicon wafer template (20x20 mm^2) with cylindrical pores (D_{MLLA}/L_{MLLA}=100/150, 1000/1500 μm) in a square pattern and a MLA film (either convex or concave) were used. The process to make the MLLA was similar to that used to make the MLA.

Surface profile measurement

The surface profiles of MLA and MLLA were measured using a 3D confocal laser scanning microscope (Olympus, OLS4000) and atomic force microscope (Veeco D3100) equipped with a digital signal process controller (nPoint C-300).

2. Supporting Figures

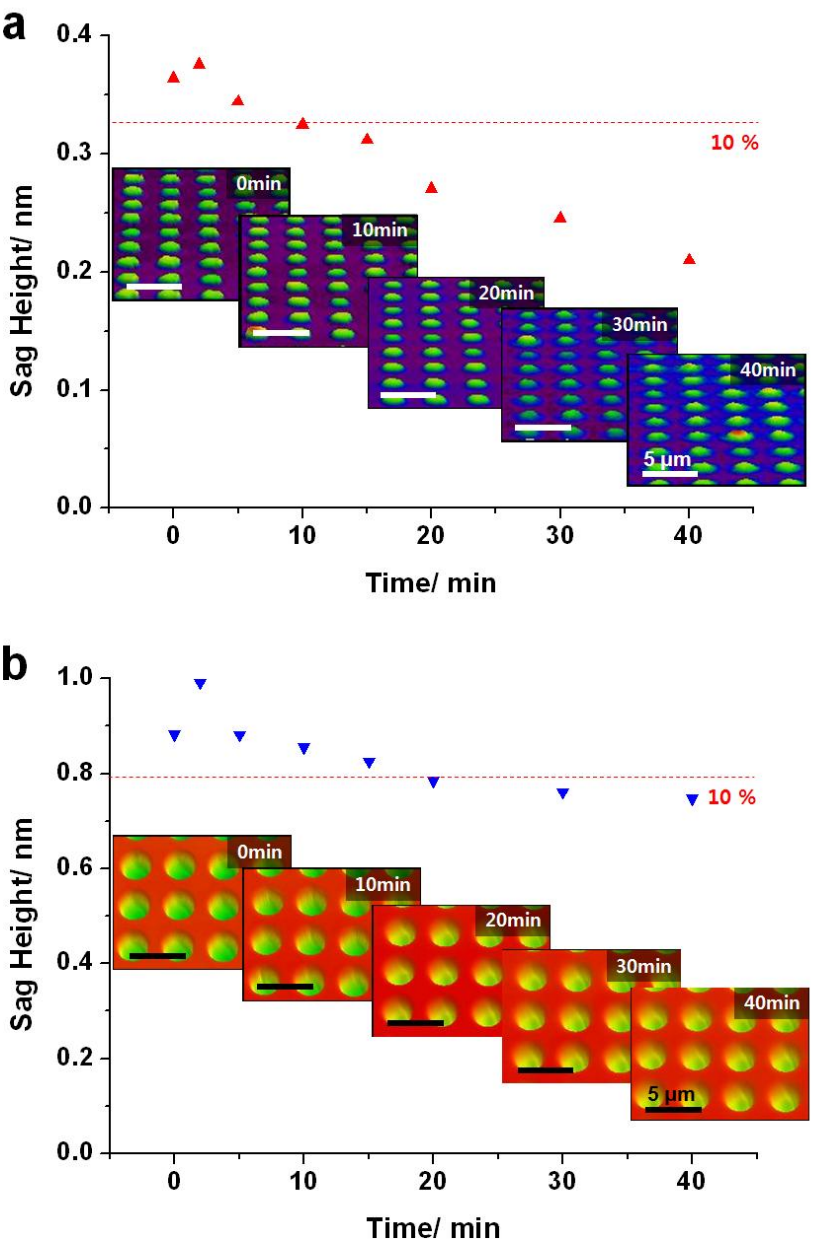

Fig. S1 Sag height of the convex (a) and concave (b) microlenses (d_{MLA}/l_{MLA}=2/3 μm) as a function of the heat treatment time at 160℃. It took approximately 10 and 20 minutes to lose 10% of the initial sag height of convex (~370nm) (a) and concave (~880nm) (b) microlenses, respectively.

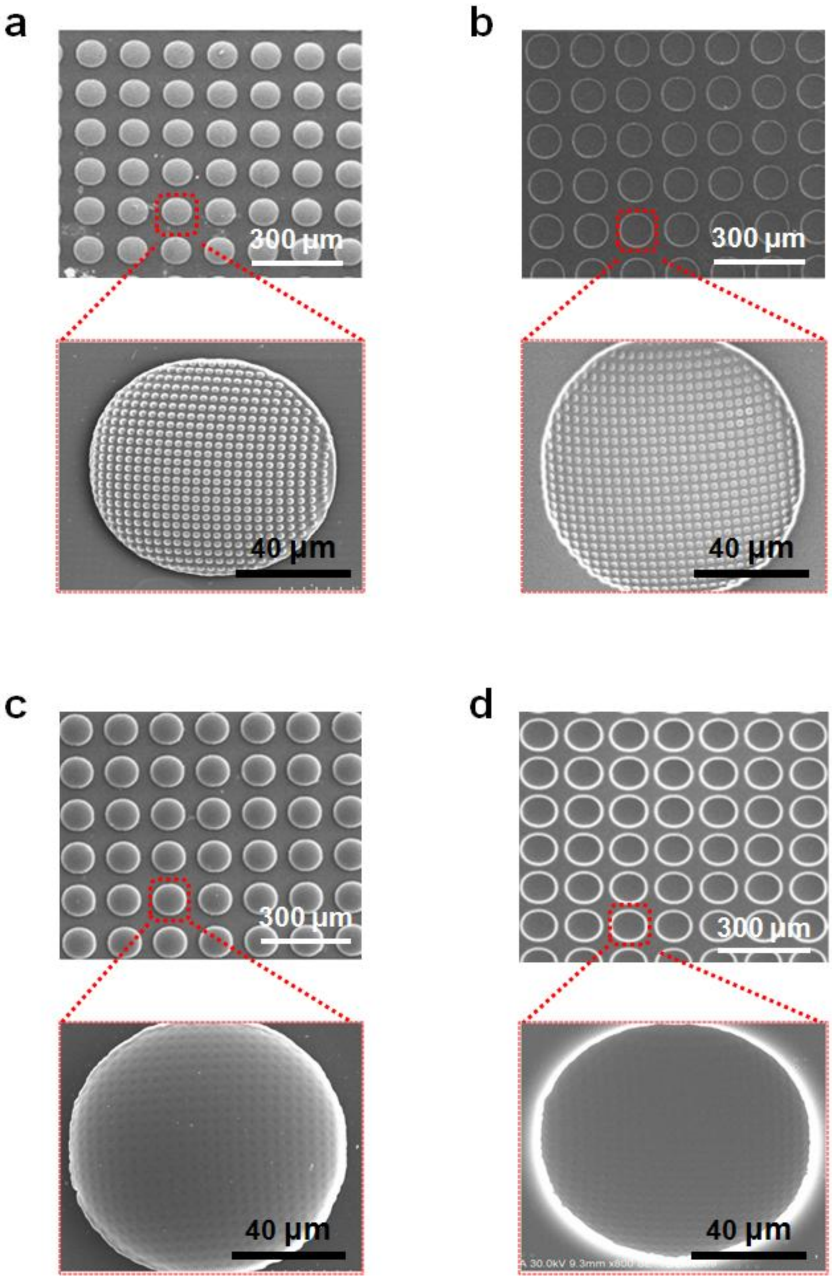

Fig. S2 Top view SEM images of the four MLLA arrays (D_{MLLA}/L_{MLLA}=100/150 µm). A large lens in each array is enlarged to show the MLA (d_{MLA}/l_{MLA}=2/3 µm) on its curved surface. (a) convex-on-convex, (b) convex-on-concave, (c) concave-on-convex, (d) concave-on-concave MLLA.

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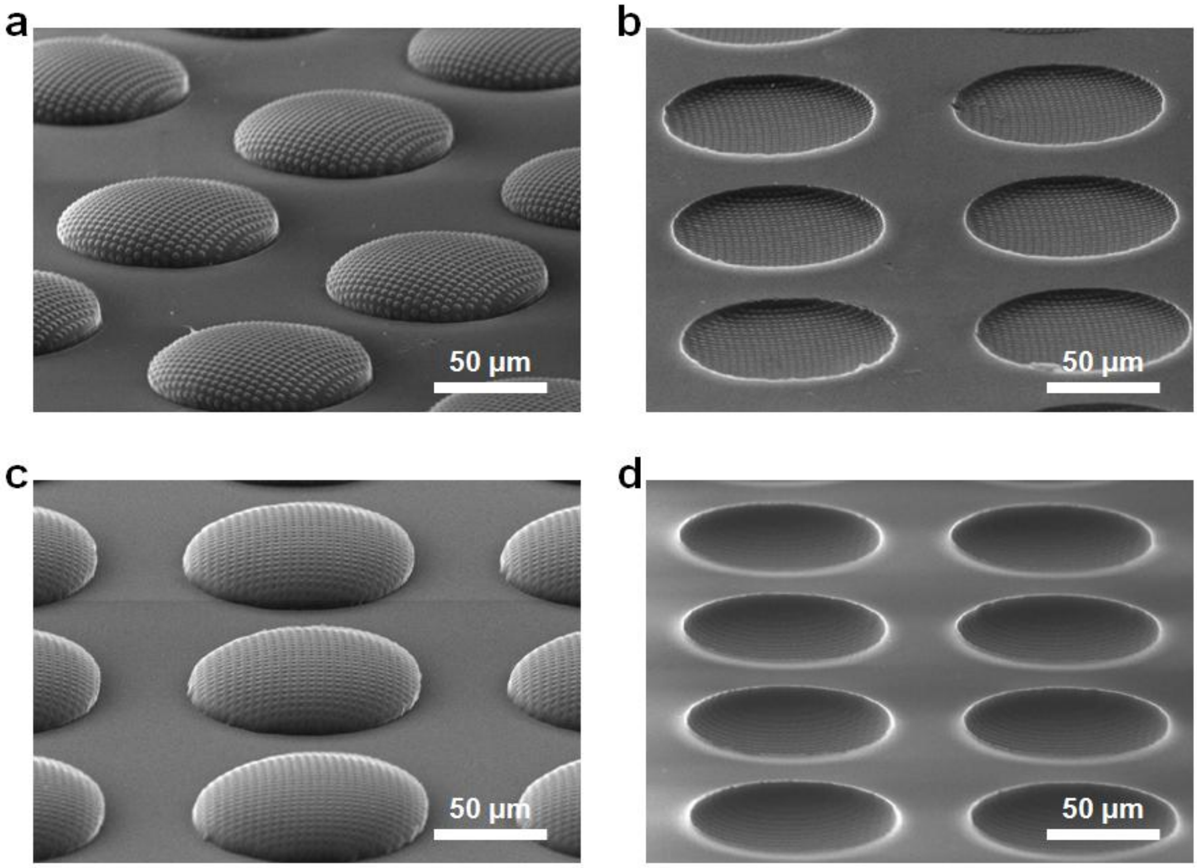

Fig. S3 Oblique view SEM images of the four MLLA arrays (D_{MLLA}/L_{MLLA}=100/150 μm, d_{MLA}/l_{MLA}=2/3 μm). (a) convex-on-convex, (b) convex-on-concave, (c) concave-on-convex, (d) concave-on-concave MLLA.

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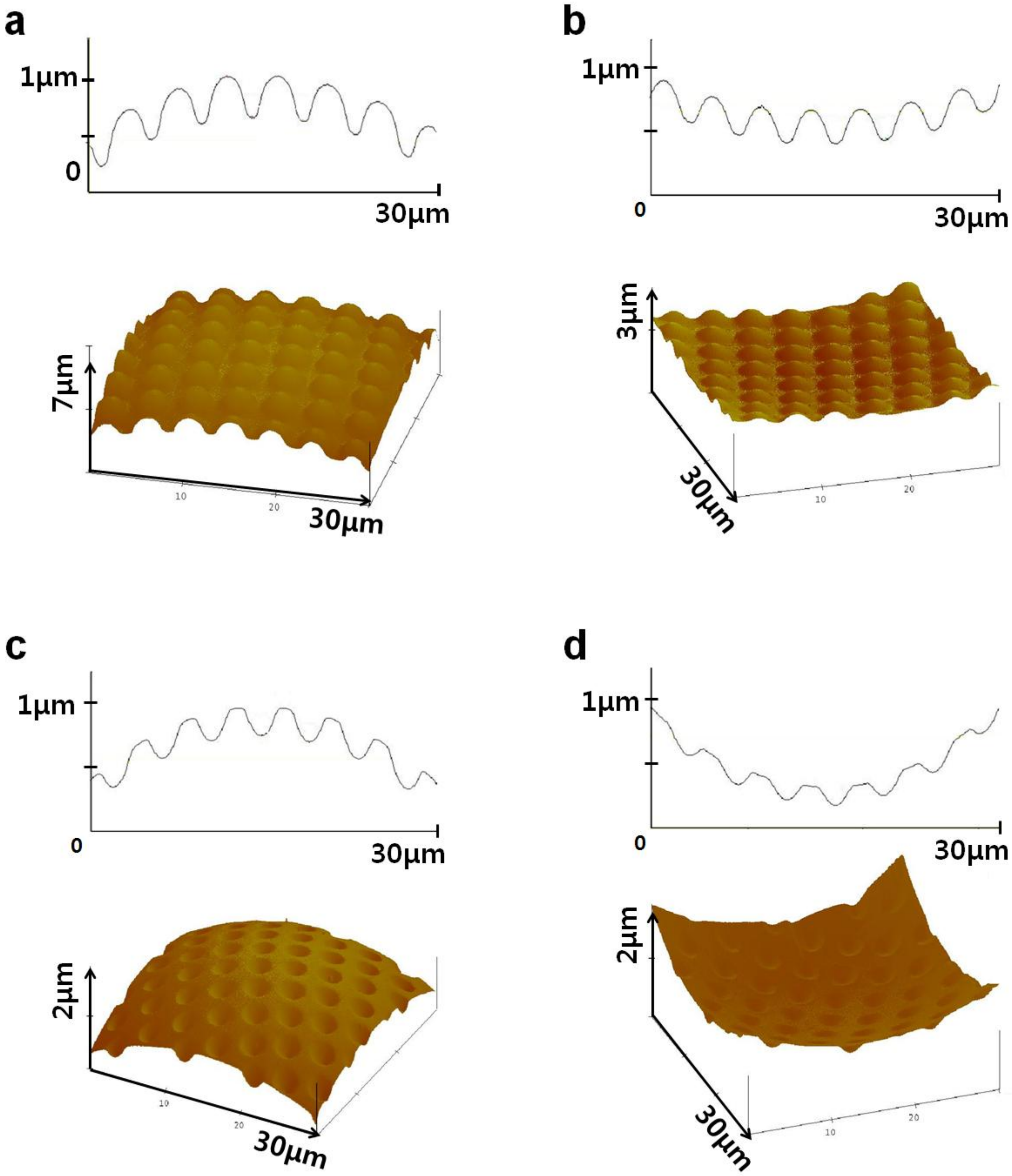

Fig. S4 AFM topography of the selected area in each array and height profiles of the sliced sections in four MLLAs (D_{MLLA}/L_{MLLA}=100/150 μm, d_{MLA}/l_{MLA}=2/3 μm). (a) convex-on-convex, (b) convex-on-concave, (c) concave-on-convex, (d) concave-on-concave.