Shape Memory Micro/Nano-Pillar Arrays for Dynamic and Optical Spectrum Dependent Transmission Control

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Shape memory polymers (SMPs) have emerged as promising materials for fabricating tunable photonic devices due to their ability to memorize a permanent shape and recover it from a programmed temporary shape. Recently, high aspect ratio SMP nanopillar arrays created via two-photon lithography have showcased their capability to convert between designed and disrupted optical transmission by bending and recovering the nanopillars. Our recent work has extended the control of optical properties by demonstrating the manipulation of diffraction patterns using micropillars fabricated through imprinting, which allows for precise control over bending direction and angles. In this study, we aim to further explore the dynamic conversion of optical properties with SMP micro/nano structures.

Polyurethane-based SMP micro/nano-pillars were fabricated from silicon master stamps by thermal imprinting at 190 °C, 150 kPa pressure for 20 min with polydimethylsiloxane intermediate stamps, resulting in permanent straight SMP pillar arrays. Micro/nano-pillars were temporarily bent by a roller at 20 °C, and recovered to their permanent straight form by heating up to 80 °C for 15 min. The micropillars primarily control the direction of light transmission. Figure 1 shows SMP micropillars with dimensions of 14 μm width, 50 μm pitch, and an aspect ratio of 6:1, exhibiting excellent transparency in the visible spectrum. Bending the micropillars redirected a portion of incident light through waveguiding and reflection.

SMP nanopillars exhibited wavelength-dependent transmission control. Numerical simulations and measurements demonstrated that bent nanopillars that had 280 nm diameter, 560 nm pitch, and 4.5:1 aspect ratio showed lower transmission in the 450-550 nm range as shown in Fig. 2. The bending of nanopillar arrays with the same direction and angle formed a metasurface, altering the wavefront of perpendicularly incident light with wavelengths between 400 and 490 nm. Consequently, blue light (480 nm) changed its transmission direction, while red light (633 nm) maintained its propagation direction, as shown in far-field projections in Fig. 3. The dynamic control enables manipulation of light propagation and transmission, with potential applications in tunable filters and beam steering devices. Integration of SMP micro/nano-pillars holds promise for even more sophisticated and powerful spectrum-dependent dynamic wave splitting.

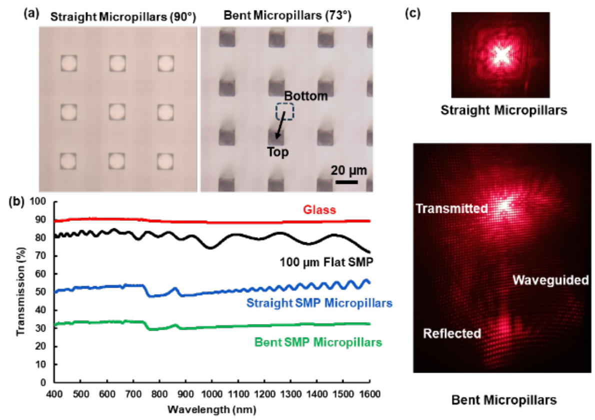

Figure 1: Optical properties of 84 µm high, 14 µm wide, 50 µm pitch shape memory polymer (SMP) micropillars. (a) Micrographs of straight and bent SMP micropillars. (b) Transmission spectra through substrate and micropillars. (c) Far field projection pattern of perpendicularly incident 633 nm laser source. Light was split by bent micropillars due to direct transmission through micropillar spacings, waveguiding by optical-fiber-like high aspect ratio micropillars, and reflection by micropillar sidewalls.

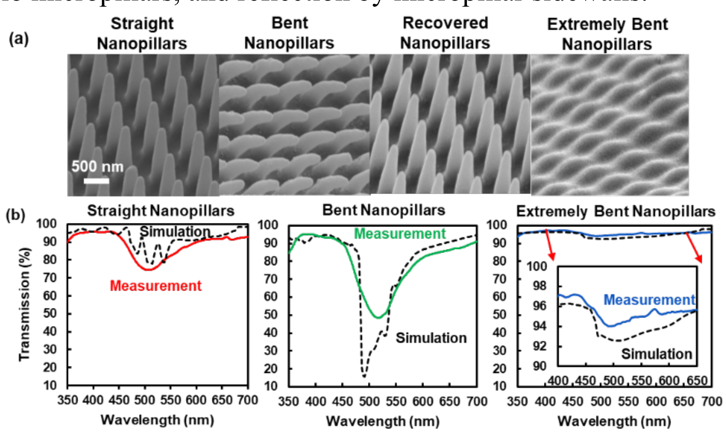

Figure 2: Optical properties of 1.3 µm high, 280 nm wide, 560 nm pitch nanopillars. (a) Micrographs of straight, bent, and recovered SMP nanopillars. (b) Simulation and measurement results of transmission at different wavelengths. Nanopillar arrays formed 2D photonic cavities which reject transmission from 450-550 nm. Transmission was altered by nanopillar bending angle.

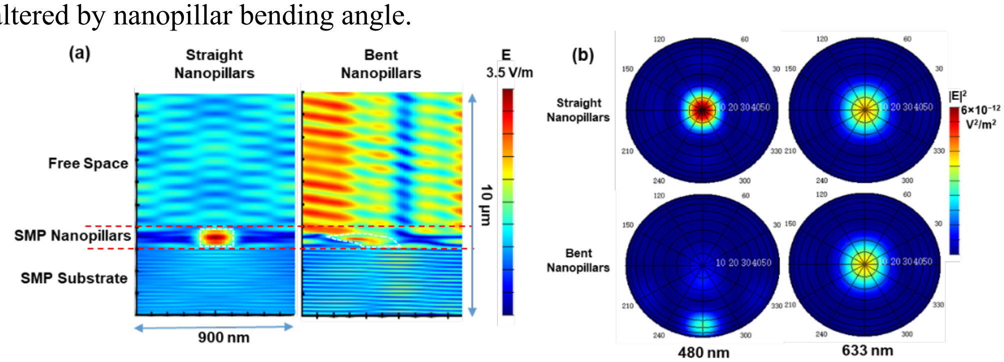

Figure 3: Far-field spectrum dependent power splitting by bent nanopillars. (a) Electrical field distribution of 480 nm light transmitting through nanopillar arrays. Wavefront was modified to tilted form by bent nanopillars. (b) Simulated far-field projection pattern of 480 and 633 nm light through nanopillar arrays. On bent nanopillars, traveling direction of 480 nm light is guided to other directions, while 633 nm light remains unchanged.