Fabrication of high aspect ratio polymer nanopillars by nanoimprint induced elongation for guided cell growth

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Nanostructures have shown increasing importance for applications in tissue engineering, bio-devices and systems, nanomedicine, and fundamental studies of cell biology. In this study, we demonstrate a nanoimprint process using demolding-induced elongation phenomena (Fig. 1) with a Si nanoporous mold transferred from anodic alumina to create high aspect ratio (~25) nanopillars of high density ($10^{10}/cm^2$) in bulk polystyrene plates. Simply by demolding at an elevated temperature (T_d), imprinted nanopillars can be stretched vertically to obtain various lengths (Fig. 2). For example, at high demolding temperature (T_d~75°, around the reduced glass transition temperature of the polymer structures), nanopillars in the rubber-like state can be stretched to 1 μm in length (Fig. 2c), much longer than the original length defined by the mold depth (~500 nm). Due to volume conservation, the diameter of the pillars shrinks from 80 nm to 40-50 nm accordingly while stretched. The stretching process is uniform across the sample. This method provides a simple way to make polymer nanostructures of high aspect ratio which is difficult for conventional nanoimprint.

The pillar aspect ratio affects the surface wettability. Taller polystyrene pillars appear to be more hydrophobic than shorter pillars (Fig. 3) due to more air trapping in the taller pillar forest. However, a rapid O_2 plasma treatment can change the 1 μm tall pillars from highly hydrophobic (water contact angle ~130°) to superhydrophilic (water contact angle ~0°). The resulting nanotopography combines ordered pillar arrays with widely differing surface energies, providing a unique platform to study cell-substrate interactions. Human dermal fibroblasts cells were cultured on these substrates and the results show that both pillar aspect ratio and surface energies have strong effects on cell adhesion and morphology (Fig. 4). For hydrophobic surface, taller pillars yield less cell spreading and more cell clustering. In contrast, cells grow normally on the tall but superhydrophilic pillars (Fig. 4c). Differences in cell behavior on the different surfaces may be due to differences in the distribution of adsorbed growth or adhesion factors, which is likely to depend on both physical topography and surface energy. Consistent with this notion, SEM images (not shown) of the surfaces after cell culture show that for hydrophobic pillar surface, the growth/adhesion factors were not deposited onto the pillars, resulting in very poor cell growth. The surface of high aspect ratio pillars can be used in devices where cell adhesion/growth is not desired.

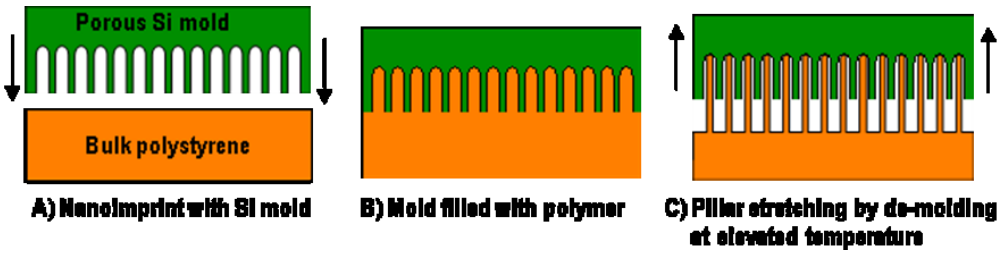

Figure 1. Schematic of the nanopillar fabrication process. The porous Si nanomold is made by transferring anodic alumina into Si by plasma etching.

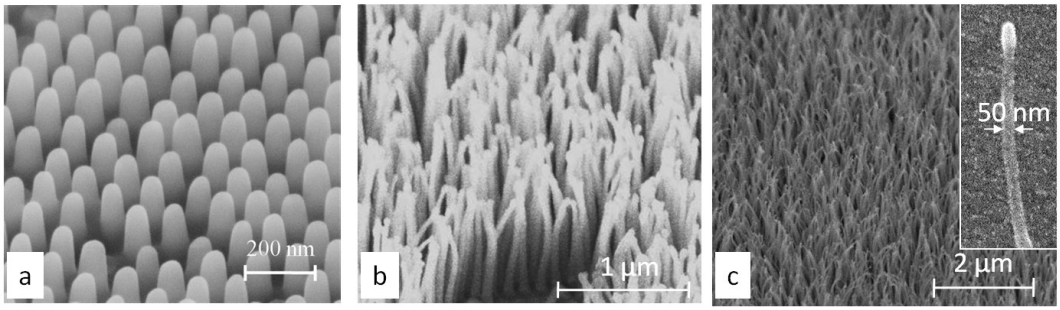

Figure 2. SEMs of pillars formed by nanoimprint and demolding at temperature T_d of a) 35°; b) 65°; and c) 75° for similar imprint conditions.

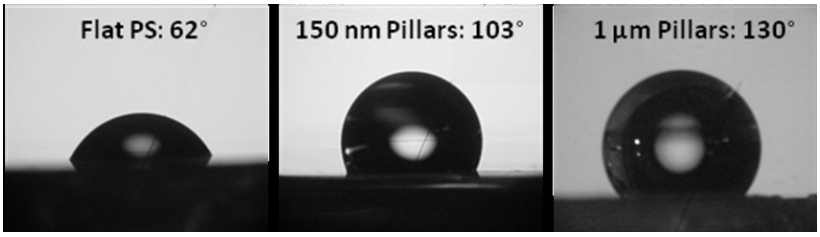

Figure 3. Digital images of water drop and measured contact angles on a) flat polystyrene; b) 150 nm tall pillars; c) 1 µm tall pillars.

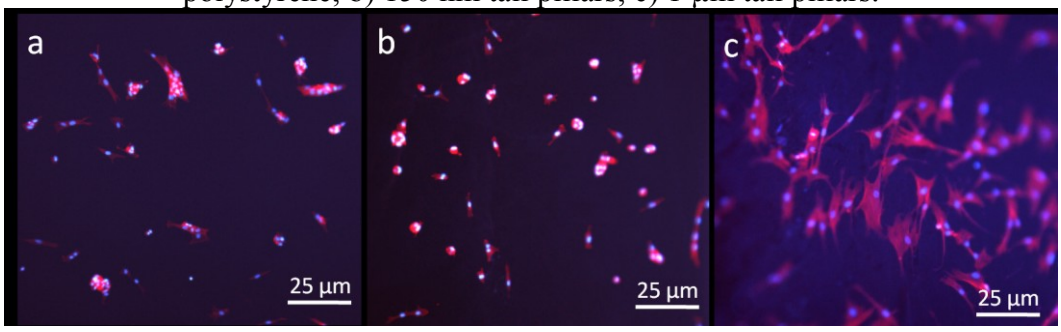

Figure 4. Fluorescence images of human dermal cells cultured on a) 150 nm tall and b) 1 µm tall pillars without O_2 plasma treatment; and c) 1 µm tall pillars with O_2 plasma treatment.