Continuous Patterns with Height Gradients by Nanoimprint Lithography and Thermal Gradient Annealing

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Besides its promise in the lithographic arena, nanoimprint lithography (NIL) is a versatile way to fabricate nanostructures for both basic research and technological developments[1]. Whether it is through thermal embossing or UV-induced crosslinking reaction, the features on the rigid mold can be replicated onto the polymer resist layer. For such a replication process, the as-imprinted structures are entirely determined by the design of the mold.

In this work, we utilize the viscoelastic properties of polymer materials to create patterns that have a gradient in the height (or depth), from the as-imprinted value to a flat film. This is achieved by annealing nanoimprinted polymer patterns under a temperature gradient. At elevated temperature, the patterned polymer surface will tend to smooth out due to the surface tension, and the rate of the pattern decay is determined by the polymer viscosity[2]. Since the latter is a function of the temperature, a gradient in annealing temperature creates a gradient of viscosity, which in turn results in a gradient of height across the pattern after annealing for a fixed amount of time (Fig 1). The direction of the height gradient can be controlled with respect to the direction of the patterned grating lines. Moreover, quantitative control of the pattern height gradient is achieved based on the understanding of temperature dependence of polymer viscosity (Fig 2). We further demonstrate that these gradient substrates have applicability as a general combinatorial measurement platform for studying surface topology effects on cellular responses (Fig 2), wettability, and adhesion.

[1] L. J. Guo, Adv. Mater. **19**, 1 (2007).
[2] W. W. Mullins, J. Appl. Phys. **28**, 333 (1957); **30**, 77 (1959).

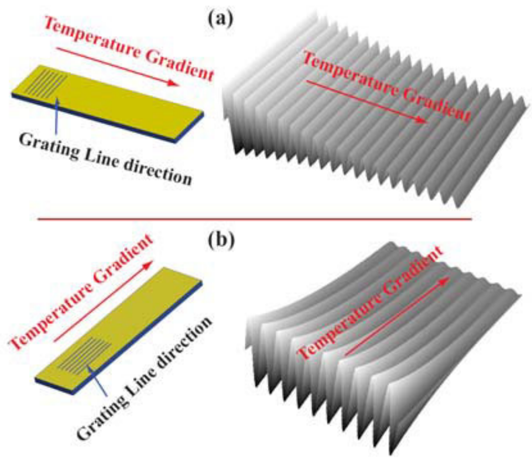

Fig 1: Schematics of gradient gratings: Annealing imprinted polymer gratings with a temperature gradient creates a height gradient on the patterns. Depending on the temperature gradient direction, the height gradient can form in the direction (a) perpendicular or parallel (b) to the grating lines.

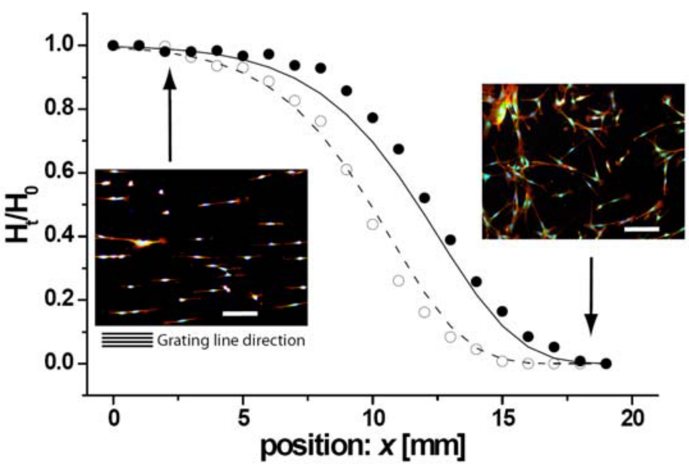

Fig 2: Quantitative characterization of the pattern height (h_t normalized by the as-imprinted value h_0) as a function of position (x) along the gradient: Symbols are AFM measurement results: filled and open circles represent 800 nm and 400 nm pitch gratings, respectively. The lines represent quantitative predictions based on polymer viscoelasticity. Insets are fluorescence images of pre-osteoblast cells (nuclei stained in green, cell body stained in red) cultured on the 800 nm pitch grating at positions indicated by the arrows; the scale bars correspond to 100 μm.