Nanopatterned Hydrogels as Model Materials to Study the Deformation Behavior of Polymer Nanostructures

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ABSTRACT

Hydrogels, which belong to the class of environmentally sensitive polymers, are used as mechanical flow valves or actuators in micro- and nanofluidic devices due to their ability to change their size and shape in response to a change in their ambient conditions. Whereas conventional photolithography and photopolymerization based approaches limit the patterning resolution of hydrogels to about a micron, our recently established direct-write electron-beam lithography enables patterning resolution to less than 100 nm. The change in size of such nanopatterned hydrogels, in response to an external stimulus, thus allows us to directly study the effects of confinement on the reliability of polymer nanostructures under mechanical stress.

Keywords: Hydrogels, e-beam, *N*-isopropylacrylamide, nanostructures, deformation

1 INTRODUCTION

The mechanical stability of nanosized polymer lines is crucial in the fabrication of an integrated circuit in semiconductor industry. Previous studies have shown the role of capillary forces in collapsing patterned lines of high aspect-ratio.[1] Destabilizing buckling modes of patterned features are directly related to their failure mechanism. Unlike other patternable materials which need an external mechanical perturbation for deformation, environmentally-sensitive hydrogels can be deformed in direct response to a change in ambient conditions.

Environmentally-responsive hydrogels are used in many applications ranging from controlling the release rate of a drug to managing flow control in microchannels. As the on-chip use of nanotechnology nears commercialization, the use of soft nanostructures will extended to other promising areas (e.g., nanofluidics, bionano devices). Pioneering work by Beebe *et al.* and other groups employed photopolymerization to microfabricate environmentally-responsive hydrogels.[2-4] But the best patterning resolution of these materials achieved using these methods is limited to 2.5µm.[5] We have recently demonstrated an effective electron-beam lithography based approach to nanopatterning hydrogels that extends their resolution further to sub-100 nm dimensions.[6]

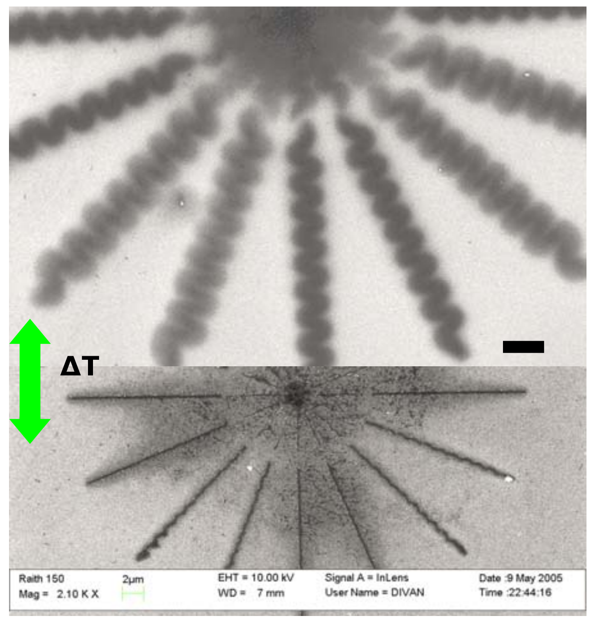

Figure 1: 200-nm patterned *straight lines* deform naturally into rotini-like features when swollen in cold water (top). The features collapse into straight-lines again when a stimulus is applied as an increase in temperature to 40 ºC (bottom).

2 RESULTS AND CONCLUSIONS

Poly (*N*-isopropylacrylamide) (PIPAAm), a well studied thermoresponsive hydrogel, undergoes a volume collapse transition at 32 ºC in water. Therefore, we crosslink the linear PIPAAm chains using focused electron-beam in a dry state, "develop" the uncrosslinked regions in water below 32 ºC. However, cold water causes the PIPAAm nanopatterns to swell and increases their effective size. The developed nanopatterns are thus deswollen in water above 32 ºC to regain their original shape. Figure 1 shows the swelling induced changes observed in patterned nanolines of PIPAAm. The features were written to be straight-lines but deform into *rotini*-like features after swelling, without debonding from the silicon substrate. Interestingly, the shape after deformation is similar to that recently proposed to explain the sub-Rayleigh phonon propagation modes in nanoimprinted polymer lines.[7] The mechanical reliability of patterned polymer nanostructure can thus be studied by observing the swelling-induced deformation of hydrogels that are nanopatterned to be of different sizes and shapes.

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