Molecular scale resolution achieved in polymer nanoimprinting technique

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Scientists using molds derived from carbon nanotubes have approached the ultimate resolution – defined by molecular scale dimensions – in a widely used polymer nanoimprinting technique. By accurately replicating features with nanometer dimensions, the technique could play future roles in fabricating structures in fields as diverse as microelectronics, nanofluidics and biotechnology.
Polymer nanoimprint lithography works by pressing a mold with embossed relief structures against a thin polymer film. Little is known, however, of the basic physics and chemistry that operate between the two surfaces at the molecular level, let alone how these interactions relate to resolution.

"A better understanding of the basic physics and resolution limits of nanoimprint lithography will allow us to develop design criteria for better polymer materials for molds and films that would improve the performance," said John Rogers, a professor of materials science and engineering at the University of Illinois at Urbana-Champaign and a researcher at the Beckman Institute for Advanced Science and Technology.

In a paper published in the December issue of the journal Nano Letters, Rogers and colleagues at Illinois and Dow Corning Corp. explored the fundamental resolution limits of polymer nanoimprint lithography. The work involved a broad interdisciplinary collaboration between experts in several fields, including nanoimprint lithography, carbon nanotubes, nanoscale imaging techniques for polymers, and polymer chemistry.

The researchers began by growing single-walled carbon nanotubes on a silicon wafer. Then they prepared a mold of the nanotubes by pouring a thermal-setting polymer over the wafer.

After curing the mold, they gently pressed it against a thin layer of photocurable polyurethane. Passing light through the transparent mold caused the material to cross-link and harden. The researchers then used atomic force microscopy to measure the heights of the resulting relief structures and transmission electron microscopy to determine their widths.

“Our approach allowed us to reach a critical size regime never explored before,” Rogers said. “From a detailed analysis of the microscope images, we were able to demonstrate reliable patterning at the 2 nanometer scale, and even some capability down to 1 nanometer. These dimensions are comparable to the sizes of individual macromolecules.”

To obtain features with a resolution of 2 nanometers, both the average distance between polymer cross-links (approximately 1 nanometer) and the lengths of individual chemical bonds (approximately 0.2 nanometers) become important in the molding process.

“We normally wouldn’t be concerned with the molecular structure of the polymer,” Rogers said, “but at these dimensions we have feature sizes that are only a few times larger than the length of individual bonds in the polymer. In addition, we have a countable number of polymer bond lengths that are available to replicate the relief structure.”

By varying the density of cross-links in the polymer, the researchers also established a connection between resolution limit and molecular structure of the polymer. “The ultimate resolution is correlated to the ability of the prepolymer to conform to the surface and the ability of the cross-linked polymer to retain the molded shape,” Rogers said.

The ability to mold nano-scale features can benefit many fields, from semiconductor device manufacturing to emerging areas of biotechnology. For example, polymer nanoimprint lithography could help the electronics industry achieve the resolution requirements needed for next-generation devices. By structuring materials with dimensions smaller than the wavelength of light, the technique also could create photonic devices whose optical properties are defined by the geometry of the relief structures embossed on them.

In other applications, polymer molds with molecular scale channels could prove useful in nanofluidics, where the tiny tunnels would transport fluids or separate materials based on size, Rogers said. And, by allowing for the nanoimprinting of individual macromolecules, the technique might open new paths to molecular recognition, drug discovery and catalysis.

Source: University of Illinois at Urbana-Champaign (by James E. Kloeppel)

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