Concepts for roll-to-roll inline optical metrology enabled by computationally inexpensive simulations of polymeric microembossing and nanoimprinting

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We have developed a set of extremely fast computational techniques for simulating the imprinting and embossing of micro- and nano-scale patterns into layers of polymeric materials. The techniques are scalable to complex geometries containing many millions of features and can be used to guide the design of processes for manufacturing microfluidics, integrated circuits, photonics, and functional surfaces.

The modeling approach encapsulates the polymer's time-dependent behavior using an analytical function for its surface deformation when loaded at a single location. Meanwhile, the embossing/imprinting stamp and the substrate or web are well modeled as linear-elastic. Our approach takes a spatially discretized representation of the geometries on the stamp and finds polymer and stamp deflections in a series of iterative steps.

I will describe how this modeling approach has been applied to the hot micro-embossing of relatively high-molecular-weight amorphous thermoplastics for microfluidics manufacturing. I will also describe applications in simulating nanoimprint lithography, including recent developments of the model that incorporate the spreading and coalescence of tens of thousands of picoliter-volume droplets of photocurable resin between a stamp and a substrate. I will then discuss how these mechanical process models could be used to design process-monitoring diffractive optical elements that could be incorporated unobtrusively into embossed/imprinted patterns. These process monitors would impart information to an illuminating laser beam about the performance of the embossing process, and could diagnose specific processing issues such as pressure nonuniformity, incomplete cavity filling, and demolding defects.