# Nanocoining – Seamless nanopatterned drum molds for roll-to-roll nanoimprint lithography

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Roll-to-roll (R2R) nanoimprint lithography (NIL) can enable the scalable manufacturing of exciting technologies that until now have been limited to lab-scale demonstrations. However, R2R NIL has been traditionally limited by the difficulty and high cost associated with the production of nanopatterned drum molds. Smart Material Solutions' (SMS) patented process – nanocoining – overcomes this obstacle by enabling seamless nanopatterning around the outside of a drum at rates exceeding 1000 $mm^2$/min, more than 500 times faster than electron-beam lithography. Nanopatterned surfaces manufactured with these drum molds can have unique optical and wetting properties that can be applied to a variety of commercial products including AR/VR optics, OLEDs, biosensors, wire-grid polarizers, and solar panels.

Nanocoining owes its exceptionally high patterning rate to an ultrasonic indenting process whereby the nanopatterns on a diamond die are stamped into metal tens of thousands of times per second (Figure 1). First, a focused ion beam (FIB) mills the nanofeatures into a diamond die. The diamond die is then mounted on an ultrasonic actuator that indents the nanopattern into a rotating metal drum 45,000 times per second, each time replicating the diamond's nanopattern into the metal surface. The resulting nanopatterned drum mold (Figure 2) can be used to rapidly nanopattern very large areas using R2R NIL.

SMS will present its most recent results on diamond nanofabrication, mold indenting with its nanocoining pilot system, and the patterning of functional plastic films with its molds. Advances in the nanofabrication of the diamond dies have enabled nanopillars with pitches ranging from 100 nm to 5 μm, gratings with spacings down to 140 nm, and hierarchical features (nanofeatures on top of microfeatures). The pilot system, designed by SMS and fabricated in partnership with Aerotech, Inc. and Professional Instruments, Inc., is a multifunctional diamond-turning lathe and indenting system capable of producing seamless cylindrical drum molds as well as foil shims that can be flattened or wrapped around a drum. Finally, plastic films replicated from SMS's molds exhibit advanced properties such as a broadband increase in transmission caused by the motheye effect.

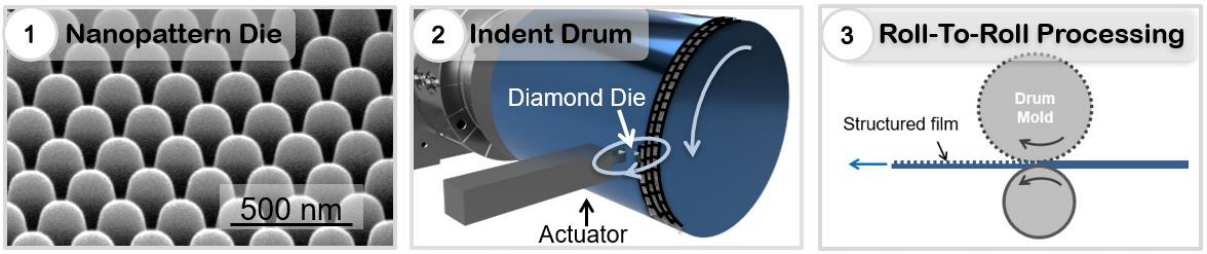


**Figure 1.** The nanocoining process. 1) A focused ion beam (FIB) mills the nanofeatures into a diamond die, and 2) an ultrasonic actuator indents the nanostructured die into a rotating metal drum 45,000 times per second, and 3) nanostructures are rapidly replicated using roll-to-roll or plate-to-plate processes.

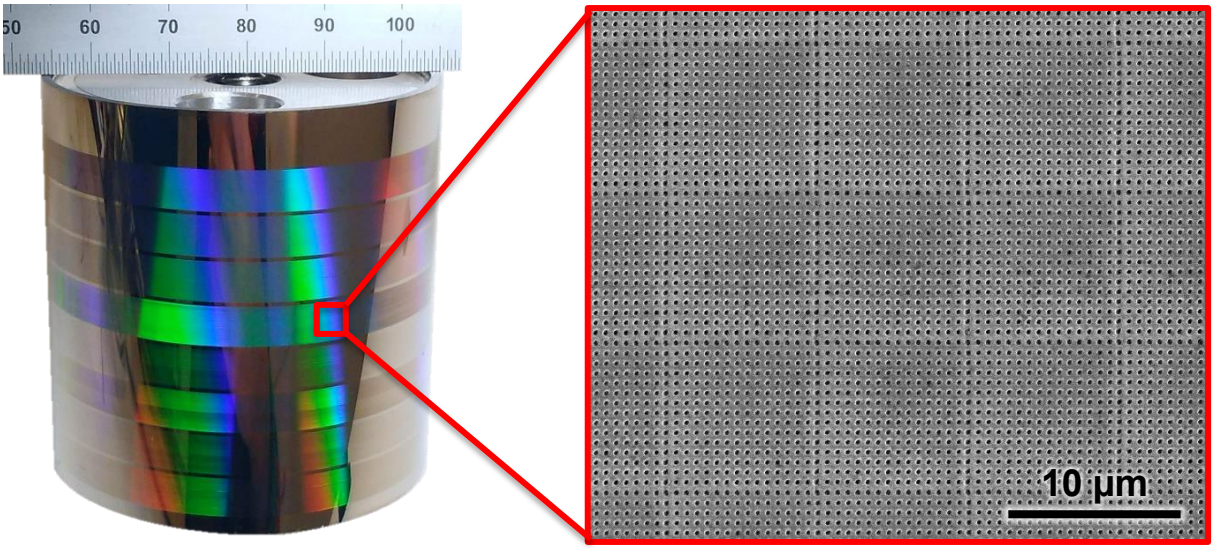


**Figure 2.** A prototype drum with several nanopatterned strips (left), and an SEM image showing about 15 registered indents from a diamond die with features on a 600-nm pitch (right).