Large-Area Nanopatterning with Focused Ion Beam Milling, Nanocoining, and Roll-to-Roll Thermal Embossing

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Nanoscale patterns change the way materials interact with their environment, often resulting in extraordinary material properties that enhance applications ranging from solar energy and virtual reality to anti-dust and anti-microbial surfaces. Traditional patterning processes like electron-beam lithography have been instrumental in demonstrating these exciting material properties, but more scalable processes are needed for high-throughput nanomanufacturing. Here, we present the nanopatterning of very large areas (> 250 ft^2) using a combination of focused ion beam (FIB) milling, nanocoining, and roll-to-roll (R2R) processes.

This scalable nanopatterning process involves rapidly and seamlessly copying small-area nanopatterns to create very large-area patterns. First, a FIB mills patterns such as periodic arrays of bumps, microlenses, or pyramids into the tip of a diamond die (Figure 1). The high-speed nanocoining process then seamlessly tiles indents of the nanopatterned die around the outside of a rotating cylinder using an ultrasonic actuator that vibrates at 50 kHz, creating 50,000 indented copies of the die's pattern every second and resulting in a high coverage rate of about 1 in^2/min (Figure 2). Finally, the resulting nanopatterned cylindrical mold is installed on a R2R thermal embossing or R2R UV nanoimprint lithography (UV NIL) setup to nanopattern large-area polymer films (Figure 3).

This talk will present the FIB milling, nanocoining, and R2R nanopatterning processes used for high-throughput nanomanufacturing. We will also discuss the performance of our nanopatterned films in applications such as moth-eye anti-reflective films, dust-mitigating surfaces, plasmonic metamaterial absorbers, and solar panels (Figure 4).

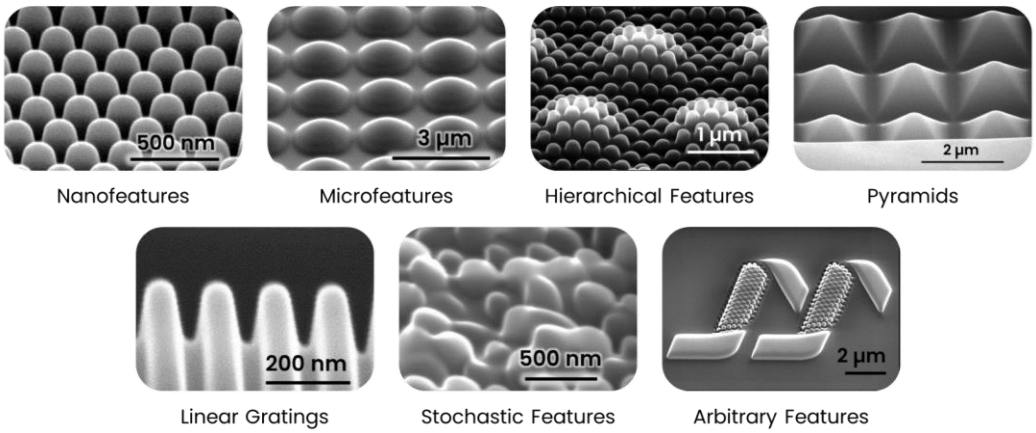

Figure 1: FIB-milled patterns: Examples of nanopatterns FIB milled in diamond.

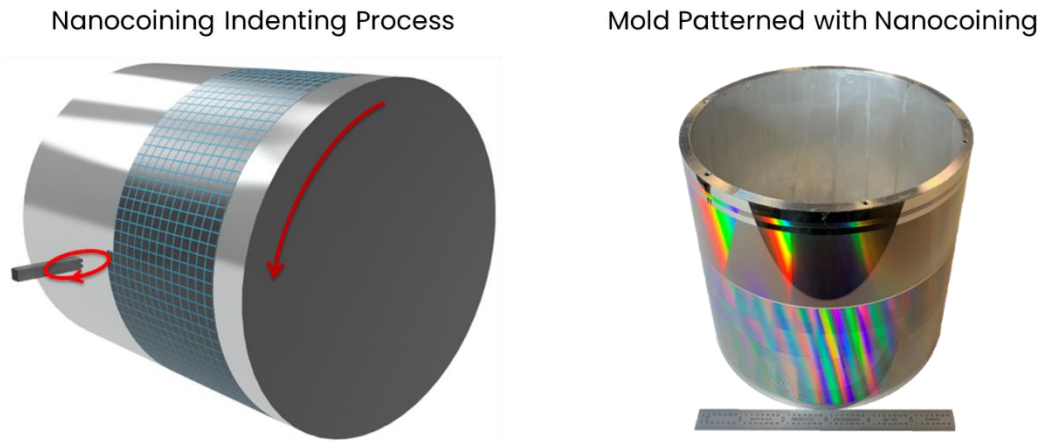

Figure 2: Nanocoining process: Illustration of the nanocoining process in which indents of a nanopatterned die are tiled side-by-side around the outside of a rotating cylinder (left) and photo of a 6-inch-diameter mold nanopatterned with nanocoining (right).

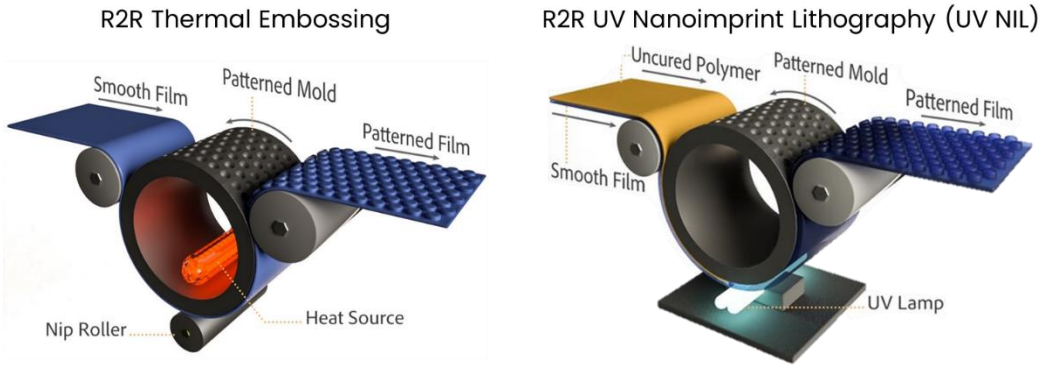

Figure 3: R2R nanopatterning: Illustrations of R2R thermal embossing (left) and UV NIL (right).

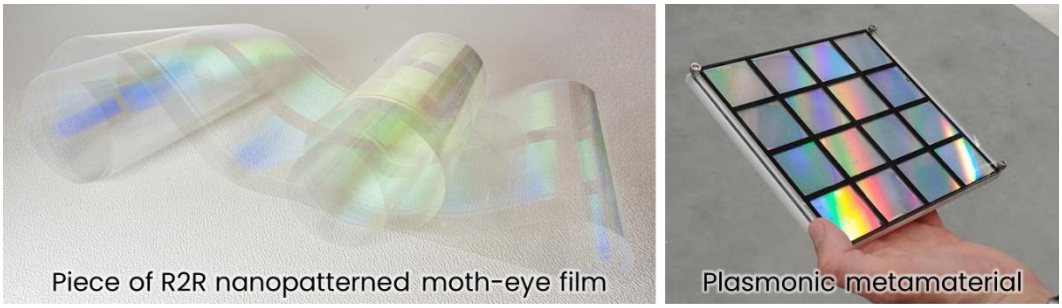

Figure 4: Example nanopatterns: Piece of 500 feet of nanopatterned moth-eye film created with R2R thermal embossing (left) and a large-area plasmonic metamaterial absorber created with nanocoining (right).