A decade of research in Nanoimprint and its applications

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Since its inception in 1995, Nanoimprint has now become the only alternative to EUV lithography for deep-nanoscale Si electronics, after world-wide efforts in the last 30 years. Nanoimprint can go beyond Si chip fabrication and beyond wafer scale applications. This talk summarizes the main effort and outcome in nanoimprint related research at the University of Michigan between 2000 ~ 2010.

A fruitful collaboration in the early 2000's led to the development of reverse nanoimprint, where resist materials is coated on a nanoimprint mold and transferred on to a substrate, eliminating the high-pressure process in thermal NIL. It also allows imprinting over non-flat or existing patterned structures.

To be able to pattern various sizes and densities, we developed a hybrid mask-mold approach for NIL. A light exposure after NIL followed by developing can eliminate residual layer without RIE. Resist materials and surface energies are key to successful patterning with low defects. By collaborating with Dow Corning scientist, we developed several resist formulations for NIL, including UV curable liquid resist for low-pressure NIL, fast thermal curable high modulus PDMS, Si-containing copolymers and silsequoxane resists. To produce nanoscale high aspect ratio (*e.g.* 10:1) structures, polymer strength needs increase, e.g. by rubber-toughened epoxy polymers.

By collaborating with experts in the bio-field, we developed protein nanopatterning by NIL, and forming of nanofluidic channels via a single step nanoimprinting over a sealing material layer, which was used for guiding microtubule transport using kinesin motor proteins, and for DNA stretching, respectively.

We paid more attention to the photonics application from the beginning. Nanoimprinted polymer waveguide and optical microring resonators were demonstrated in 2002, which was applied to biochemical sensing and sensitive acoustic and broadband ultrasound detection. Later we demonstrated simplified approach to make flexible polarizers, and developed flexible large area transparent electrodes in the form of metal nano-meshes by NIL, which was used for OLED devices. NIL was also used in our initial efforts to make structural color, which spurred much interest in the photonics field. These applications came with new demand of manufacturing nanostructures at low cost and high speed, which motivated us to develop continuous large-scale roll-to-roll NIL on flexible substrate and roll-to-plate imprinting on rigid substrate. These works have generated new knowledge in nanoengineering and created new capability for real world applications.

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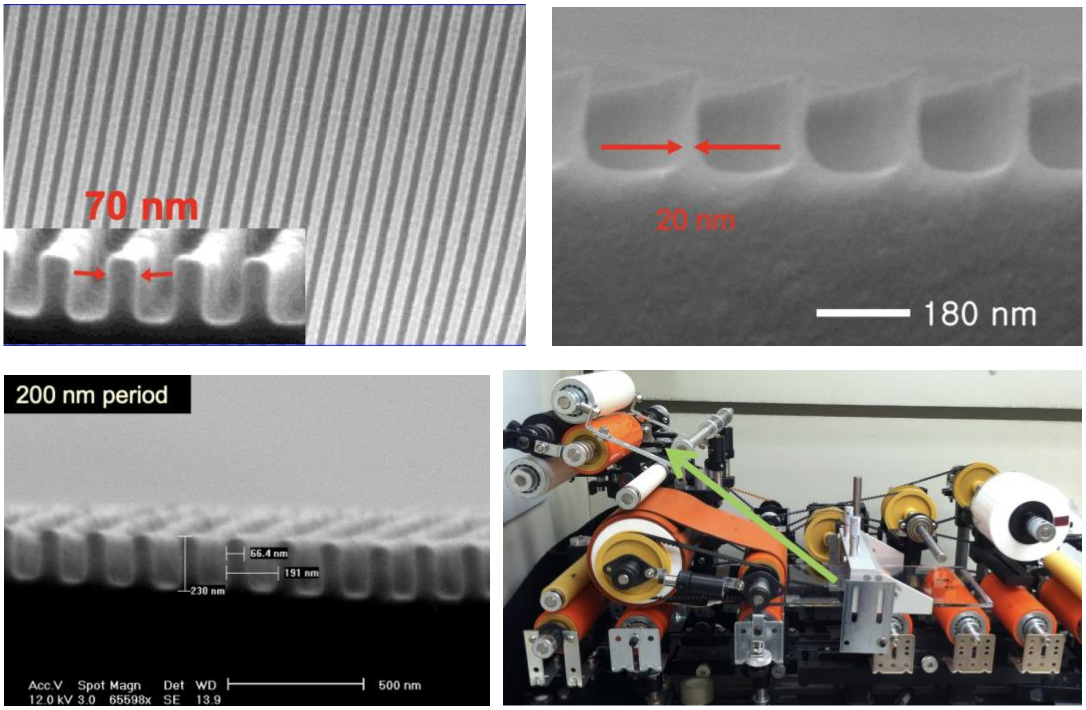

Figure 1. Top, NIL patterns by fast thermal curable PDMS and rubber-toughened epoxy imprint resist. Bottom: patterns made by the R2RNIL (*Adv. Mater.* 2008) and the 6" wide R2R imprinter (AC*S Nano* 2009)

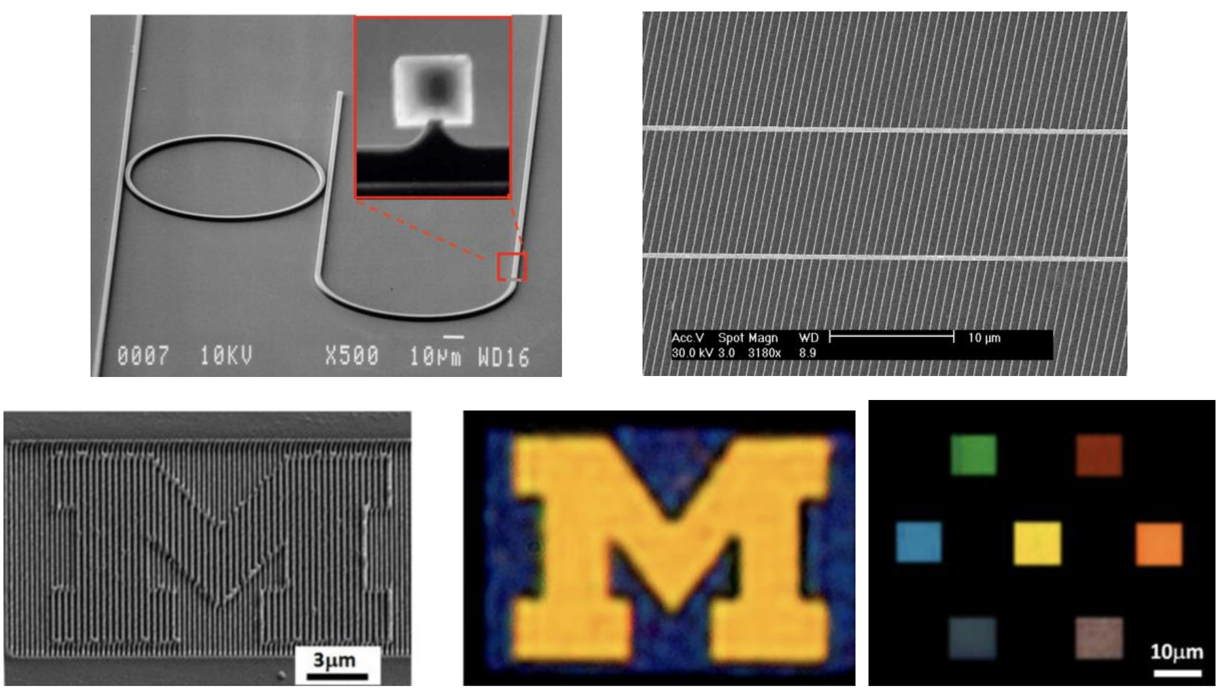

Figure 2. Top: integrated polymer waveguide and microring resonators; and metal nano-mesh transparent conductors. Bottom: structural colors realized by sub-micron pitch metal-dielectric-metal stacks.