Sub-30 nm Roller Nanoimprint Lithography Using Flexible Hybrid Molds and Applications to Large-Area High-Performance Nanoplasmonic Sensors and Solar Cells

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Roller nanoimprint lithography (RON) [1] has the advantages of large-area, high-throughput and low-cost. Here we report (a) a roller nanoimprint machine we built, (b) fabrication of large area (4" width) flexible hybrid molds with either with PDMS or PFPE front surface for the roller nanoimprint, and (c) their applications in fabrication of nanoplasmonics (e.g. solar cells, LEDs, and sensors) of sub -30 nm features.

The RON machine (Fig 1) comprises (1) one 6"-diameter steel active roller mounted by a large-area polymer hybrid mold as the master roller mold; (2) two 2"-diameter rubber-covered passive rollers as the gap control roller and the separation roller, respectively. (3) an adjustable spring mechanism that insets a force between the gap control roller and the roller mold as the imprint pressure; (4) a UV lamp for curing, permitting fast curing for NXR-2030 UV resist (Nanonex).

The hybrid molds are large-area flexible 175 µm-thick sheets of PET with two different types of materials for the mold front (imprint) surface: (i) Q-siloxane cross-linked PDMS; and (ii) bi-functional PFPE, which deliver sub-30nm feature resolution, surface treatment free, ideal chemical resistance and good release. A hybrid mold (Fig 2A) consists of (a) 35µm thick front layer (with nanopatterns); (b) 20µm adhesive middle layer and (c) 175µm PET substrate film. A low-cost, high-throughput and fast step-and-flash fabrication method of 4"-width hybrid mold has been successfully developed (Fig 2B) with sub-30nm pattern resolution (Fig 2C).

Using the RON machine and the hybrid molds, we fabricated 30 nm-thick gold large-area metal-mesh electrode with subwavelength hole-array (MESH) of 175 nm diameter, 25 nm spacing, and 200 nm period on PET substrates for plasmonics applications, in particular, new 3D cavity antennas, termed "Disk-coupled Dots-on-pillar antenna-array" (D2PA) [3] and "Plasmonic Cavity with Subwavelength hole-array" PlaSCH [2] . The MESH was fabricated by a fast approach (Fig 3A): (1) One-step UV RON patterning of 200nm-pitch pillar array in NXR-2030 layer on PET substrate (pre-coated with NXR-3022 primer layer), using a high-quality Polymer hole mold (Fig 3B); (2) RIE residual layer etching and a normal Au E-beam evaporation; (3) One fast Ultrasonic-assisted lift-off creates Au MESH on the substrate with a clean and uniform profile (Fig 3C and 3D).

Clearly, the RON system, the large-area polymer hybrid mold, and the process can be extended to other nanofabrication with low-cost and high-throughput.

Reference:
[1] H. Tan, A. Gilbertson, and S. Y. Chou, *J. Vac. Sci. Technol. B* **16**, 3926 (1998)
[2] W. Li, and S. Y. Chou, Opt. Express **19**, 3925 (2011)
[3] S. Y. Chou, and W. Ding, Opt. Express **21**, A60 (2013)

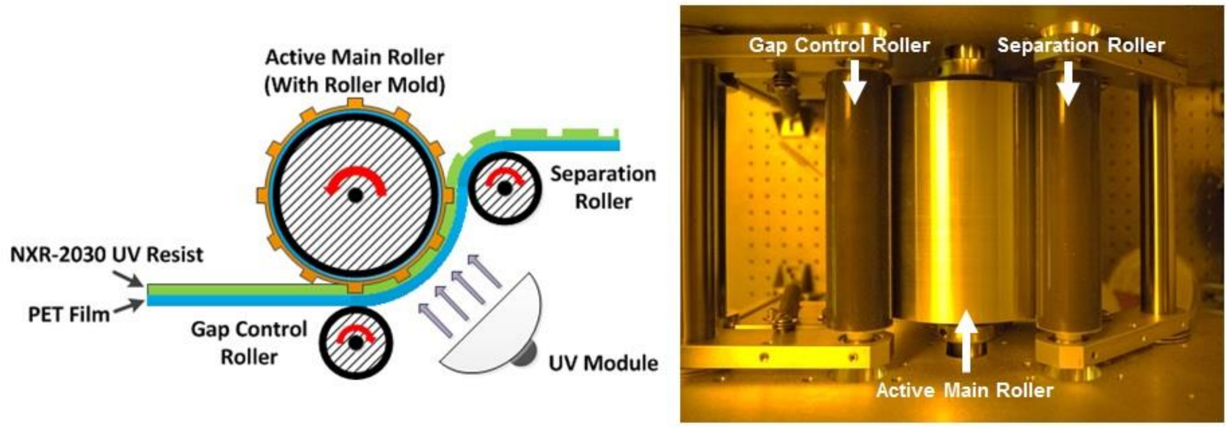

Fig. 1. Schematics of RON system, and photo of roller modules.

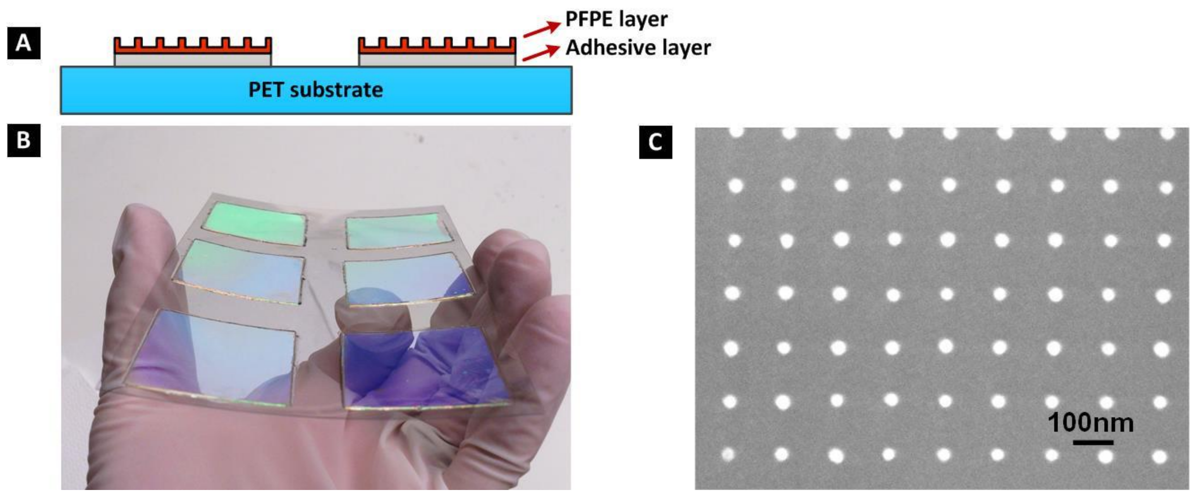

Figure 2 PFPE hybrid mold: (A) mold schematic; (B) image from a part of hybrid mold with 400nm-pitch grating patterns in PFPE layer; (C) sub-30nm pillar patterns on the mold.

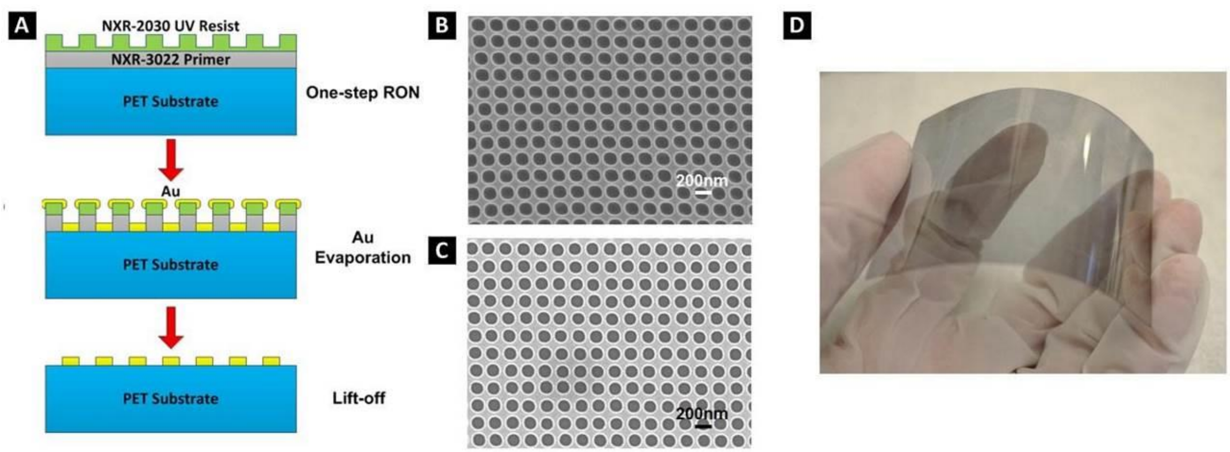

Figure 3 RON-based Au MESH fabrication for PlaSCH applications: (A) Fabrication schematics; (B) SEM image of a 200nm-pitch roller mold with 175 nm-hole patterns; (C) SEM of a fabricated 30nm-thick Au MESH on PET substrate; (D) image of a MESH sample.