Continuous fabrication of large-area flexible metamaterial via Roll-to-Roll nanopatterning for IR filter applications

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Nanoscale patterns can be utilized to optoelectronics, photonics, and bio-sensing applications. Nanoimprint technology realizes high-throughput fabrication of nanopatterns with great reproducibility and scalability at smaller scale beyond what photo- or e-beam lithography can achieve. Previously we demonstrated continuous, large-area fabrication of nanograting structures through Roll-to-Roll (R2R) nanoimprint technique[1]. In R2R, a flexible grating mold wrapping around a roll makes a conformal contact to another roll where a substrate coated with UV-curable resist is attached, and produces a well-replicated pattern as the rolling proceeds under UV illumination at the outlet. This process enables the continuous creation of large-area nanopatterns for rigid and flexible substrates at high speed.

We capitalize this simple, high-throughput, and fully-scalable process to the continuous fabrication of a large-area, flexible metamaterial array comprising metal (i.e., Al) disks patterned on the dielectric (i.e., SiO_2) layer over a background Al layer. A large-area flexible mold having hole patterns was first fabricated by stamping a 4"-wafer scale Si master onto a PDMS bed, and was wrapped around a roll in 6"-compatible R2R machine (Figure 1a). A thin layer of UV-curable epoxy-silsesquioxane (SSQ) [2] was coated on a flexible $Al/SiO_2/Al/PET$ substrate and attached to another roll which then conformally contacts the mold-mounted roll under slight pressure. The R2R process was conducted at the high speed of as fast as 10 cm/s under instant UV curing to form SSQ dot pattern. Due to excellent conformal contact, the residual layer of SSQ was controlled very thin and easily removed by RIE. Subsequent wet or dry etching of the top Al layer leads to the Al disk pattern on the SiO_2 surface over the underlying Al layer (Figure 1b).

Attributed to the disk patterns having various sizes based on our design and few defects produced in the fabrication, the fabricated metamaterial array demonstrates the desired IR filtering performance (Figure 2). The IR reflection spectrum also correlates with the simulation results by COMSOL. Our method opens a facile route to fabricating large-area flexible metamaterial devices at low cost and high speed.

ACKNOWLEDGMENTS
This effort was partially supported by Air Force Research Laboratory contract FA9551-11-C-0033.

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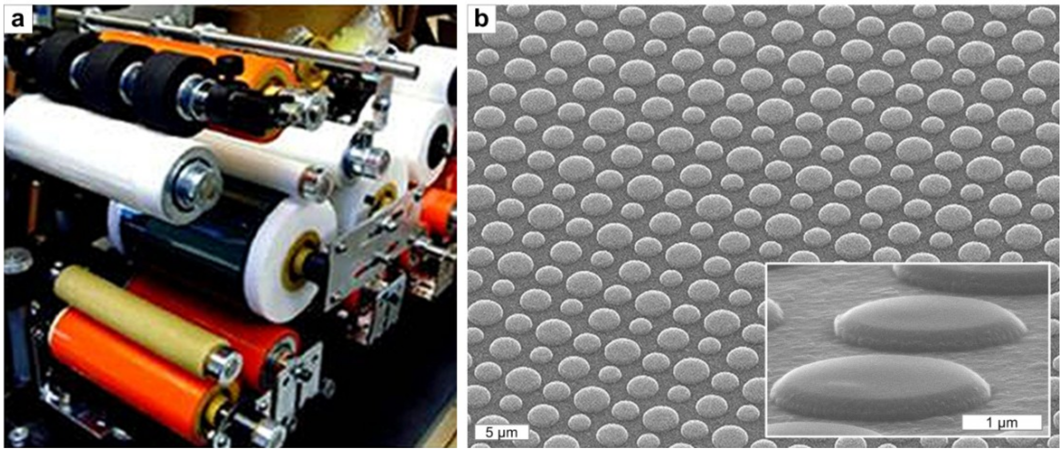

Figure 1: (a) A 6"-compatible R2R nanopatterning system that can continuously imprint nanoscale patterns on both rigid and flexible substrates at very high speed. (b) SEM image of Al disk array patterned on SiO2/Al/PET substrate via R2R process. Inset to (b) shows the tilted view of Al disks.

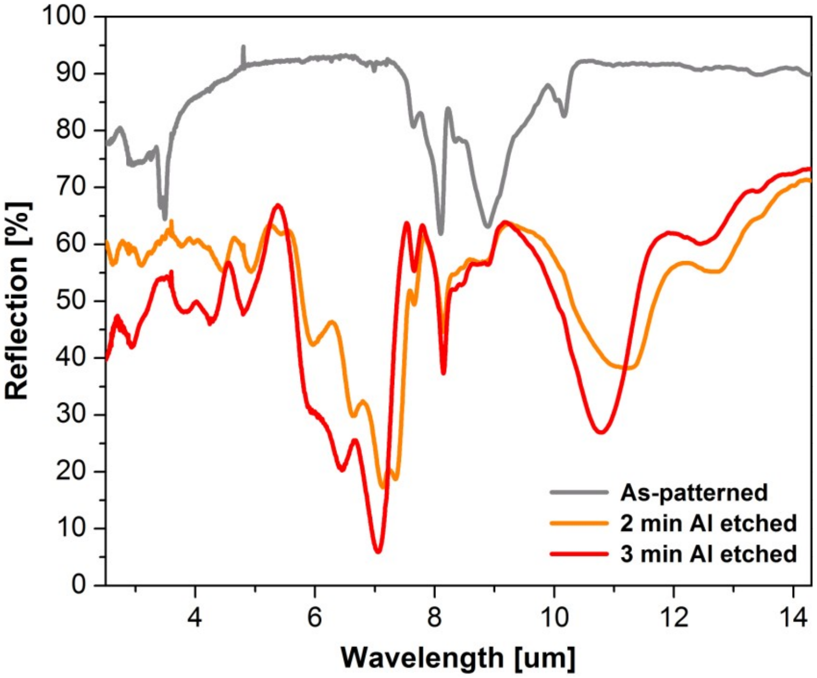

Figure 2: Reflection plot at the mid-IR range, measured by FT-IR: The IR reflection is suppressed down to ~5 % at the wavelength of 6-7 µm range, demonstrating the IR filtering performance. A wide, superposed dip is attributed to the various sizes of Al disk patterns.