Systematic study of high throughput fabrication of nano holes and nano pillars in polymer foils by roll-to-roll-extrusion coating.

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Development of large area roll-to-roll (R2R) nanostructuring methods are driven by memory storage devices, hologram security stickers, flexible electronics, graphene electrodes, and organic solar cells. The most established technology is roll-to-roll UV-assisted nanoimprint lithography (R2R-UVNIL)[1]. This method is limited in the choice of materials due to the requirement of photo-curability. The throughput for current R2R-UV-NIL systems is ~$0.2 m^2 s^{-1}$. Another widely used technology is R2R hot embossing (R2R-HE)[2]. Implementing R2R techniques, for large area nanostructuring of functional biomimetic surfaces such as superhydrophobic, anti-reflective, structural color effects is a challenge today due to the relatively low throughput of R2R-UVNIL and R2R-HE. This paper investigates a novel R2R process for nanostructuring, known as roll-to-roll extrusion coating (R2R-EC), having productivity rates, potentially, exceeding $5 m^2 s^{-1}$ (Figure1) [3].

In this investigation, the structured roller was made by mounting a nano-structured Nickel (Ni) shim onto the cooling roller (Figure 1). The Ni shim was fabricated by standard DEEMO process [4], with the Si master fabricated by e-beam lithography and deep reactive ion etching. Here we report on the replication of both nano holes and nano pillars in different thermoplastic polymers. Different sets of processing parameters were studied to assess their influence on the replication fidelity, specifically, the influence of cooling roller temperature, line speed and counter roller force (example in figure 2). Our Initial studies indicate Polypropylene (PP) replicates the best for the parameter range used in the investigation. However, the process parameters had to be tightly optimized to achieve complete replication. So far, nanostructures down to 80nm have been successfully replicated, with high fidelity, by this process. The limiting factors for proper replication were found to be the surface tension induced radius of curvature of the polymer melt and the retardation time for crystallization of the polymer melt.

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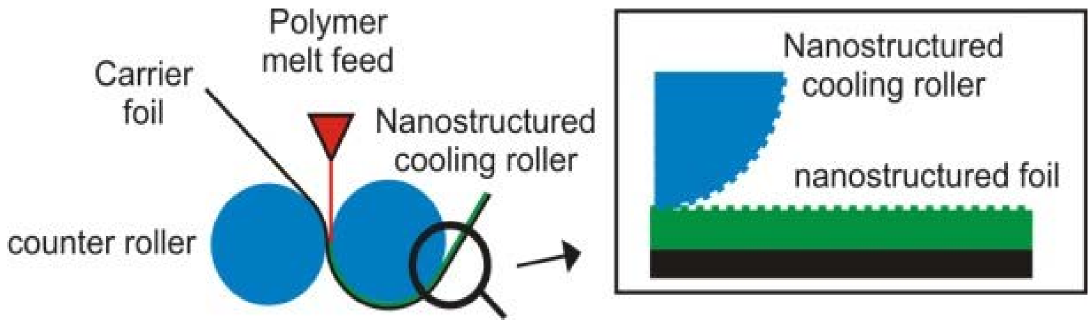

Figure 1: Schematic of R2R-EC. Polymer is heated to a high temperature, such that it achieves a desired low viscosity. Simultaneously, pressure is applied by the counter roller against the structured cooling roller, which is kept well below the solidification temperature of the polymer, forcing the polymer melt deeply into the nanostructures. The structured foil is subsequently wound up.

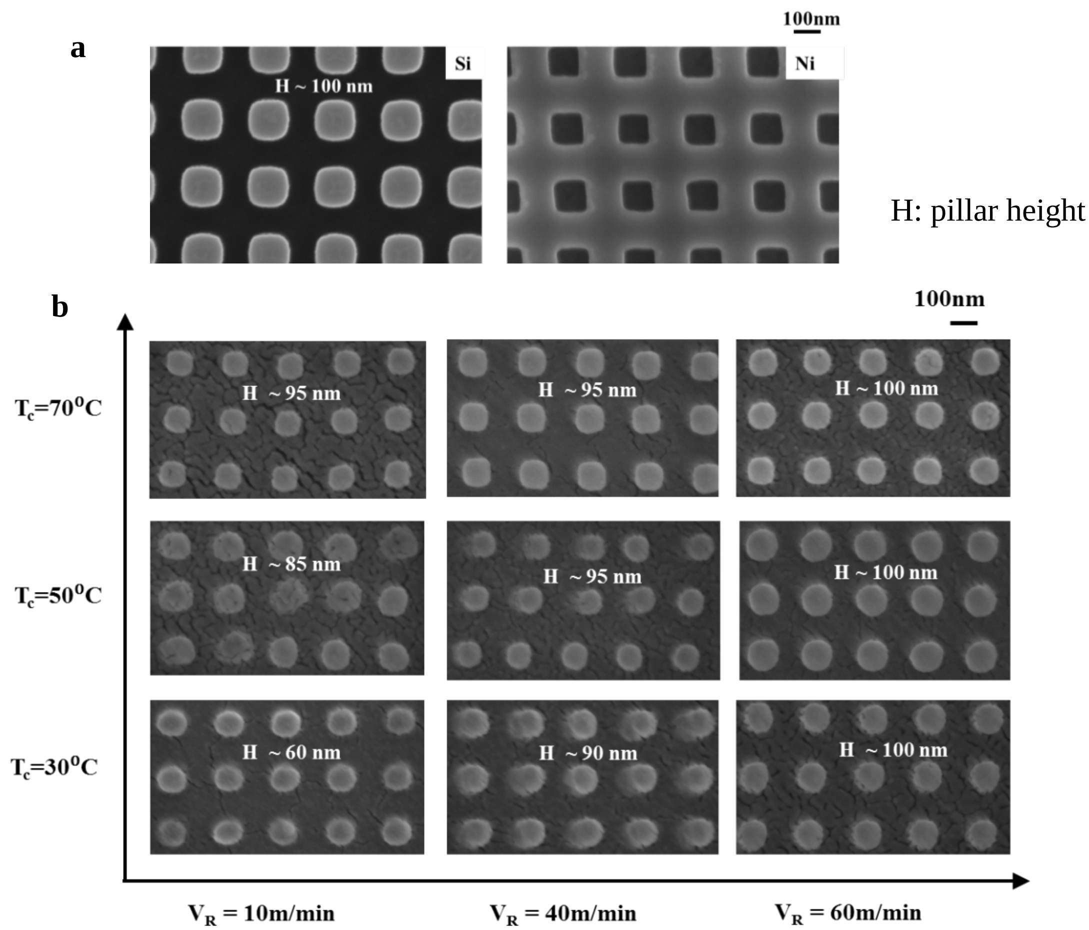

Figure 2: (a) SEM images (top view) of the Si master (e-beam lithography and deep reactive ion etching) and there after electroplated Ni shim. (b) SEM images (top view) of nano pillars replicated in PP by extrusion coating at different line speed (V_R) and cooling roll temperature (Tc), at counter roll force of 30 kN/m. An improvement in replication was observed by increasing Tc and V_R. Complete replication was achieved for V_R: 60m/min and Tc: 70^0 C.