Systematic Study of Roll-to-Roll Colloidal 3D Nanolithography System and Its Applications

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Periodic three-dimensional (3D) nanostructures are important for applications in photonics, porous material, and nanofluidic filters, and can be fabricated using multiple-beams interference lithography [1] or phase-shift lithography [2]. Another promising method is using closed-packed nanospheres as a near-field optical element [3,4] to generate complex 3D intensity pattern as described by the Talbot effect, which can be used to expose underlying photoresist. In recent work, we have demonstrated a novel method to continuously fabricate periodic nanostructures by integrating automatic Langmuir-Blodgett assembly and scanning lithography system in a roll-to-roll approach. Initial results have shown the successful printing 3D nanostructures over large areas with high uniformity (~90%). However, the quantitative analysis and further applications of this system are still unexplored.

In this work, we examine the patterning precision of this system over long time and large area. To examine the process repeatability, the defect-free areas are analyzed using image processing and statistical analysis over a long period of time. In these experiments, the same colloidal suspension and patterning parameters are used, and the scanning electron microscope (SEM) images of each sample are recorded and analyzed. Each particle in the SEM images is categorized according to its nearest neighbors, allowing the identification of the connection and defect modes. Figure 1(a) to 1(c) show the analysis process, which includes marking the centroid of each particle and calculating the individual connection mode. We tracked the assembly process for more than a month, and the closed-packed, defect-free areas and its variation are shown in Figure 1(d)-(e). The data demonstrates while the initial patterning is not uniform, the defect density ameliorate over time. The assembly statistics over large areas will also be examined.

We will also investigate repeatable large-area patterning onto various soft and flexible substrates and explore strain-tunable optical properties. In the proposed process, the geometry of the 3D periodic nanostructure can be controlled by altering the relative ratio between the particle size (300 – 1000 nm) and the laser wavelength (405 nm laser diode). Photography and SEM images of initial results are shown in Figure 2. The diffraction colors in Figure 2(a) and 2(b) show the area of periodic nanostructure patterned on the polyethylene terephthalate (PET) and polydimethylsiloxane (PDMS) film. Figure 2(c) shows the SEM image of the nanostructure in photoresist on the PDMS. Initial testing illustrates that the structures are periodic, however the defect density increase as a function of strain. We will present detailed characterization of structure fidelity and optical properties during the stretching process. This proposed process is an efficient method which may make 3D nanostructures over large area on flexible substrates and can find applications in stretchable and wearable photonics.

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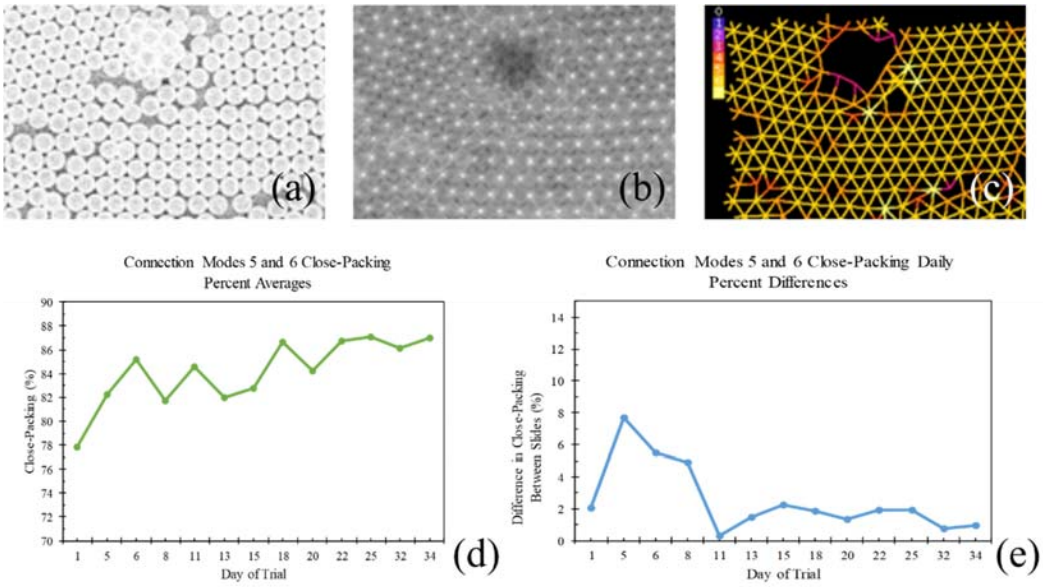

Figure 1. Quantitative analysis about repeatability using (a) top-view SEM image, (b) particle centers marking, (c) connection mode identification. The (d) defect-free area fraction and (e) its variation can be examined over several days.

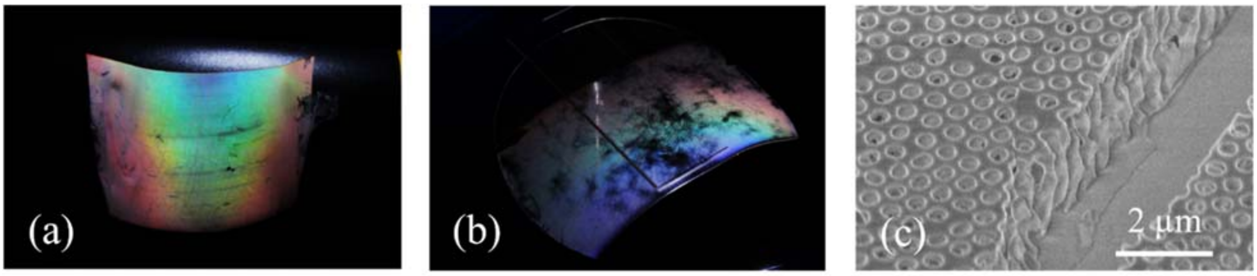

Figure 2. Periodic 3D nanostructure on various substrates: (a) periodic nanostructures on PET film, (b) periodic nanostructures on PDMS, (c) SEM image of the nanostructures on PDMS.

References:

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