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BLOCK COPOLYMERS AND NANOSPHERE LITHOGRAPHY AS A BOTTOM-UP FABRICATION TOOL FOR FACILITATING DETERMINISTIC LATERAL DISPLACEMENT

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With the capability to separate red blood cells and nano-scale exosomes, deterministic lateral displacement (DLD) has established itself as a powerful utility in biological separation applications on both the microscale and nanoscale. Current methods of employing DLD on the nanoscale require electron beam lithography and top-down fabrication methodologies. An alternative bottom-up approach for fabricating DLD-capable particle separation arrays is proposed through the use of block copolymers and nanosphere lithography.

The term block copolymer (BC) is used to describe the covalent bonding of two different polymers into a single copolymer chain. When exposed to higher temperatures via a timed thermal annealing step, BCs separate from one another in a predictable manner and self-assemble into unique thermodynamic equilibrium structures. Such structures include lamellae, cylinders, and spheres, with each structure existing in arrays both parallel and perpendicular to the substrate surface. The respective lengths of each polymer within the BC can be manipulated during copolymer synthesis to control the resulting structure and domain spacing of the final equilibrium formation. The self-assembly process of each particular structure depends significantly on factors such as composition (F_{St}), film thickness (δ), annealing temperature (T), and non-preferential surface treatment. Through precise conditioning, the final separation formations can be predicted for each BC, and the end result can be used as an etching mask to transfer the self-assembled polymer pattern onto a more resilient substrate material. The self-assembly of BCs is characterized exclusively within the nanoscale range due to thermodynamic limitations on the macroscale, suggesting the potential utility of BCs as a fabrication tool for creating nanoscale DLD arrays.

Nanosphere lithography (NSL) denotes the use of organized, hexagonally close-packed nanospheres to act as a patterning mask in fabrication techniques such as lithography and deposition, allowing for the predictable imprinting of organized nanoscale features in the areas between each nanosphere. Nanosphere layers are often comprised of polystyrene beads, which can exist as both monolayers or multilayers across the substrate surface. Layered nanosphere surfaces are contrived using a variety of methods, such as spincoating or dropcoating, though most methods require an empirical understanding of the nanosphere application process in order to create large domains of defect-free, hexagonally close-packed nanosphere layers. Though, with its foundations in creating organized nanoscale features onto a substrate surface, the use of NSL is also considered as a fabrication tool for nanoscale DLD arrays.

Designs plans for fabricating DLD-capable arrays are developed for both BCs and NSL, selecting a polystyrene and poly(methyl methacrylate) (PS-*b*-PMMA) block copolymer and polystyrene (PS) beads as choice materials for each respective process. However, fabrication plans using BCs are not implemented due to budget and design limitations; the price of BCs are beyond the scope of our funding, and the implementation of fabricating a DLD-capable particle separation array using BCs require a difficult two-step photolithography alignment procedure. Thereafter, the fabrication of NSL-formed DLD arrays is pursued, aiming to use the self-assembling nanosphere layers as a deposition mask to fabricate nanoscale DLD microfluidic arrays. Though our goal is to obtain an empirical validation of theoretical results, existing limitations in forming large, defect-free NSL domains prevents the successful fabrication of DLD-capable arrays. To combat these physical limitations, the capabilities of both BC- and NSL-fabricated DLD arrays are instead validated through COMSOL Multiphysics Modeling simulations, where theoretically feasible final array dimensions are calculated for each methodology, simulated using particle-tracing physics, and compared against existing DLD designs and efficiencies in literature. Through this process, the ultimate viability and effectiveness of using BCs and NSL as a fabrication tool for constructing DLD particle separation arrays can be explored without the intense, empirical understanding necessary for fabricating physical devices using these processes.