Directed Fluidic Assembly of Microscale Tiles

CNF Project # 1396-05
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Abstract:
The aim of this project is to direct the assembly of micron-scale units (microtiles) into programmable, reconfigurable structures or programmable matter using hierarchical assembly and by dynamically tuning the affinities between the tiles. Here we describe the fabrication of latching silicon microtiles for directed fluidic assembly and experiments demonstrating hierarchical assembly using fluid flow through a polydimethylsiloxane (PDMS) fluid chamber. In addition, we present our work on dynamically tuning inter-tile affinity using valves based on thermorheological fluids. The operation of these valves is controlled using platinum heaters in a microfluidic chamber.

Summary:
Programmable matter refers to a novel functional form of matter where fundamental building blocks are assembled selectively in a dynamically-programmable assembly process to construct arbitrary target structures. This manufacturing paradigm offers an alternative to top-down direct fabrication methods and to static bottom up self assembly methods. Unlike most current microscale self-assembly methods, our approach uses dynamically-switchable affinities between assembling components which facilitates the assembly of irregular structures. Here we present two new experimental advances that will enable a programmable matter system: the development of a multi-chamber microfluidic chip for improved far-field assembly of sub-elements, and the demonstration of near-field inter-tile affinity switching using a thermorheological assembly fluid.

Hierarchical Assembly:
Hierarchical assembly is an effective and efficient approach to manufacturing. Serial assembly of a device or structure becomes prohibitively slow as the number of components in the structure increases. We can greatly increase the throughput of an assembly system by starting with the target structure and subdividing it one assembly task at a time until we are left with a large number of simple, independent assembly steps. Assembly then proceeds in reverse order, moving one level up the hierarchy with each assembly task. A hierarchical assembly process is also more robust than a serial process. Even without error correction, any subassembly with a component or assembly failure can be replaced without the need to replace the rest of the structure.

In previous experiments we have demonstrated the automated assembly of patterned silicon “microtiles” which 500 µm by 500 µm by 30 µm in size (Figure 1). Assembly is controlled by modulating the translational and rotational shear forces applied to the tiles by adjusting the fluid flow through a microfluidic chamber fabricated using multilayer soft lithography [1]. The fluid flow is directed through the chamber by opening and closing a series of valves on a number of different microchannels connected to the assembly chamber.

Building upon these assembly experiments, we have designed and fabricated a new microfluidic chip to investigate hierarchical assembly with hexagonal tiles with 100 µm sides and a 12 µm thickness (Figure 2). Multiple chambers are
used to manufacture and store sub-assemblies, which are then assembled into the final structures. Our goal is to demonstrate the hierarchical assembly of a nine-tile triangle composed of smaller three-tile triangles.

**Dynamically Tunable Affinities:**

The ability to dynamically tune tile affinities allows us to assembly irregular structures as well as enables error correction during the assembly process. We implement dynamic affinity switching between tiles using on-tile thermorheological valves which manipulate the local flow field within the tile. The valves are made up of an aqueous solution of a poly(ethylene oxide)_{106} - poly(propylene oxide)_{70} - poly (ethylene oxide)_{106} triblock copolymer that undergoes reversible sol-gel transition on heating [2,3]. Local heating above the critical gelation temperature results in a sol-gel transition, locally stopping the flow and resulting in a closed valve configuration. On cooling, the gel returns to solution form and flow resumes, representing an open valve configuration. As shown in Figure 3, opening and closing of these valves can be used to manipulate the location of the attraction basin around the tile controlling where the next tile attaches to the main structure. These valves have the advantage, compared to valves based on soft lithography and MEMS type devices, of minimal tile level fabrication and do not fatigue with time.

In order to demonstrate dynamic affinity switching, we have patterned a “fixed tile” of PDMS with channels through it in a microfluidic chamber and a “mobile tile” made of silicon. The assembly chamber consists of a fluidic layer fabricated in a manner similar to the one described above. This fluidic layer is bonded to a pyrex substrate patterned with platinum heaters to open and close the thermorheological valves. The platinum heaters were fabricated using lift off. SPR 220-3.0 photoresist was spun on a pyrex wafer at 3000 rpm, followed by a soft bake. A mask with the heater pattern was created using the GCA/MANN 3600F Optical Pattern Generator (PG3600). The photoresist was patterned using the EV 620 contact aligner, followed by image reversal using the YES-58SM Image Reversal oven. After a descum process on the reactive ion etching (RIE) tool, the Oxford PlasmaLab 80#1, platinum was evaporated along with a chrome adhesion layer using the CHA Mark50 E-Beam Evaporator tool. Lift off was carried out using Microposit Remover 1165. Silicon nitride was then deposited on the wafer using the IPE 1000 Plasma Enhanced Vapor Deposition (PECVD) tool and etched using the Oxford 80#1 to reveal the contact pads for external connects. The valves have been used to locally attract and repel a silicon tile as shown in Figure 4 and have also been characterized based on applied voltage.

**References:**


Figure 2: Hierarchical assembly chamber where subassemblies made up of hexagonal silicon tiles with 100 µm sides and a 12 µm thickness are brought together to form larger structures.

Figure 3: Overview of assembly procedure.

Figure 4: Assembly and disassembly of a mobile silicon tile from a fixed structure due to operation of thermorheological valves.