DIRECTED FLUIDIC SELF-ASSEMBLY OF MICROSCALE TILES

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ABSTRACT
In this paper we present a novel microfabrication method in which regular, micro-scaled units are made to self-assemble into arbitrary, reconfigurable structures. We describe a series of experiments that involve the assembly of silicon microtiles in a multilayer PDMS microchamber. By controlling the local flow conditions in a microchannel array, the attraction, bonding, migration, and rejection of individual and paired microtiles are demonstrated.

Keywords: self-assembly, microfluidic, microtile, nanofabrication, digital matter

1. INTRODUCTION
Self-assembly has the potential to provide a scalable alternative to current direct-write/ direct-manipulation microfabrication techniques [1]. One of the challenges of self-assembly is the fabrication of arbitrary (non-regular) structures such as those routinely achieved using top-down techniques. Our goal is to create a form of programmable “digital matter” in which desired structures are assembled from simple, microscale units which control their assembly by manipulating local fluidic forces (Figure 1). This self-assembly is directed by power, communication, and actuation provided to the units at the substrate. Here, we present an initial set of experiments designed to demonstrate the first layer of assembly and disassembly. Simple fluidic control is used to assemble individual and paired silicon microtiles in a PDMS microchamber. We also compare the effectiveness of various tile designs, substrate outlet designs, and assembly media.

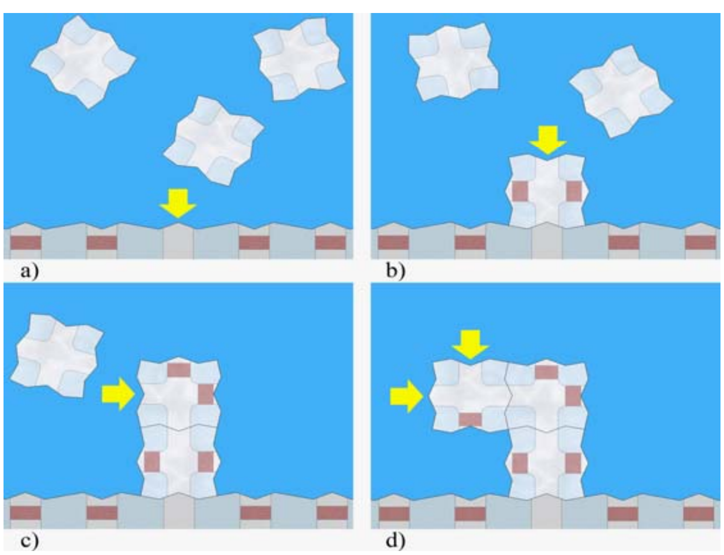

Figure 1. Directed Fluidic Self-Assembly Concept
a) Fluid flow (indicated by arrows) into a substrate attracts a nearby unit. ***b)*** Once attached, the unit draws power from the substrate to activate on-board valves (dark bands) and direct fluid flow through internal channels. ***c)*** The directed fluid attracts new units at desired locations. ***d)*** New units continue this process of directing fluid flow to assemble the next layer until the structure is complete.

2. FABRICATION

We fabricated solid, 30μm thick, square silicon tiles with lengths ranging from 100μm to 500μm by etching and releasing the top layer of a silicon-on-insulator (SOI) wafer (Figure 2, left). Two self-alignment side patterns were fabricated. The first (Figure 3e-f) is four-fold rotationally symmetric but does not align when inverted. The second pattern (Figure 3a-d) is flip-invariant but has half the potential bonding sites since each tile has two different side patterns. The multilayer self-assembly chambers were fabricated by molding a 100μm thick layer of poly(dimethylsiloxane) (PDMS) over 70μm thick positive photoresist (SU-8) and bonding it to a glass surface. Various outlet designs were tested (see Figures 3, 4) and the design with single, narrow nozzles (Figure 2, middle) was found to minimize bonding errors. A second, thick layer of PDMS with pneumatic channels was overlaid on the fluidic layer (Figure 2, right) in order to valve the outlets. This allowed precise control over the shear conditions in the chamber.

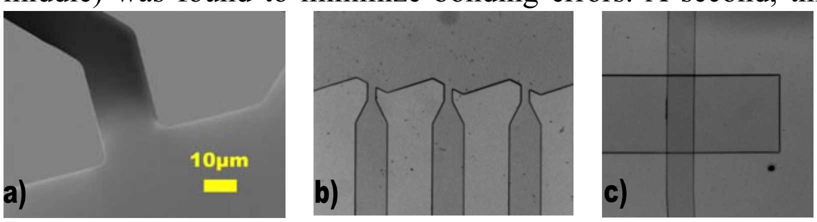

Figure 2. Fabrication of Microtiles and Assembly Chamber ***a)*** SEM image of etched 100μm Si tiles. ***b)*** Fluid outlets and patterned substrate of PDMS microchamber. ***c)*** Pneumatic channel (horizontal) overlaid on fluidic channel (vertical).

3. EXPERIMENTAL RESULTS

Single-tile experiments demonstrated our ability to attract, bond and reject a microtile from a patterned PDMS substrate (Figure 3a-d), as well as to migrate a tile along the substrate from one bonding site to the next (Figure 3e-f). In multi-tile experiments, we were able to attract tiles to the substrate, bring them together to self-assemble (Figure 4a-c), migrate the assembly along the substrate, and reject them (Figure 4d-f). Tile-tile and tile-substrate alignment was successful with both side patterns, but migration was more successful with the rotationally symmetric tiles. Tile assembly was conducted in three fluids: deionized water (Figure 4d-f), a 5% surfactant solution (Figures 3e-h,4a-c),

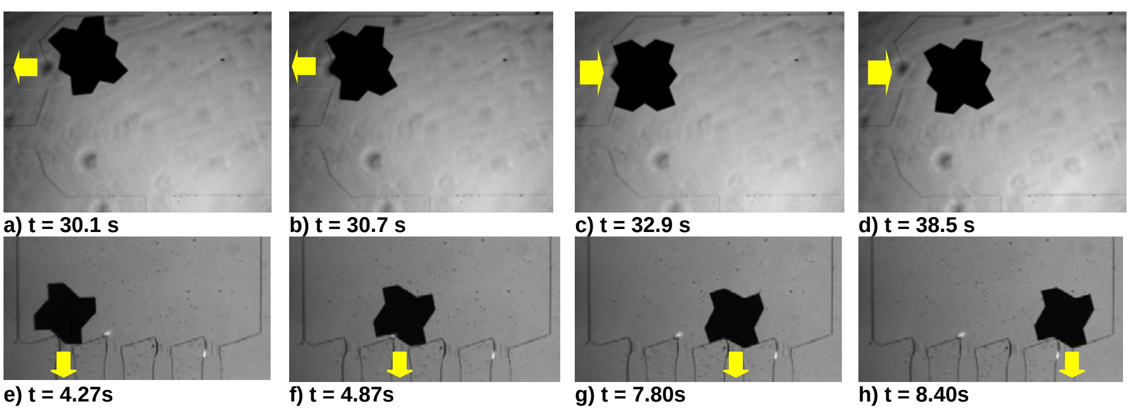

Figure 3. Single Tile Experiments *a-d)* Fluid flow (indicated by yellow arrows) into and out of a substrate channel attracts and then repels a 500 μm silicon tile in silicone oil. ***e-h)*** A 500 μm silicon tile in a 5% surfactant solution is made to migrate along a substrate by selectively opening and closing chamber outlets to direct fluid flow as indicated.

and silicone oil (Figure 3a-d). Tile movement and self-alignment was more successful in the surfactant solution and silicone oil experiment. Pressures in the range of 1-4 psi drove the flow enough to successfully move the tiles in the deionized water and the surfactant solution experiments. Much higher pressures (10-15psi) were required to manipulate the tiles in the silicone oil experiments. The pneumatic valves completely shut off fluid flow into the outlets under applied pressures in the range of 17-20psi.

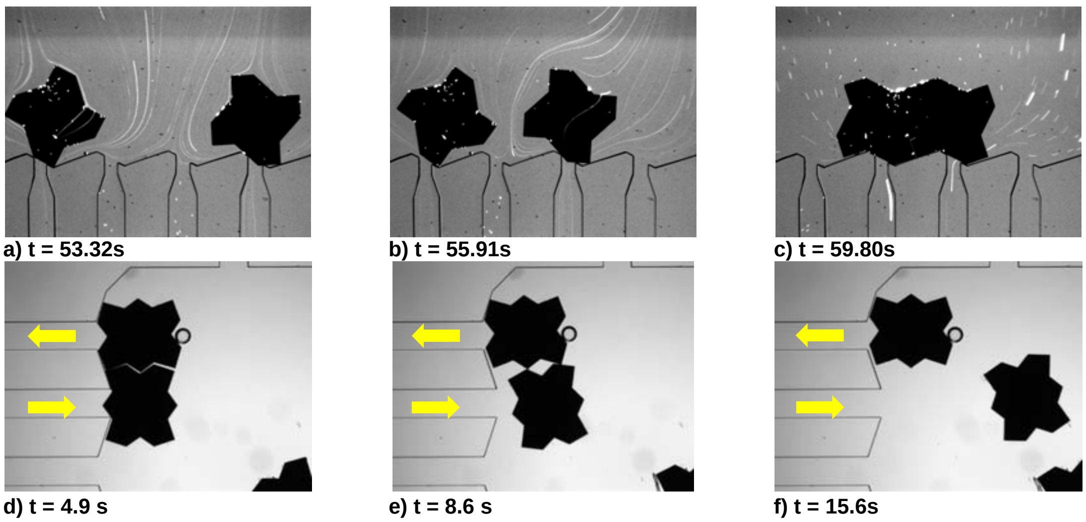

Figure 4. Multi-tile Experiments *a-c)* Two tiles are assembled on a substrate by selectively opening and closing outlet valves. 3μm fluorescent particles help visualize the assembly fluid's flow profile. ***d-f)*** Fluid flow in the directions indicated disassembles two 500μm silicon tiles in deionized water.

4. CONCLUSIONS

We have presented a new microfabrication paradigm in which structures are assembled from regular units with limited actuation and control. An initial series of experiments were described in which patterned micron-scale silicon tiles were made to self-assemble on a patterned substrate in a multilayer PDMS microchamber. Successful attraction, bonding, movement and rejection were demonstrated for individual and paired tiles. The effectiveness of various tile shapes and sizes, assembly chamber designs, and assembly fluids were compared. These experiments represent the first steps in the development of a novel microfabrication system based of directed microfluidic self-assembly.

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