ADVANCES TOWARDS PROGRAMMABLE MATTER

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ABSTRACT

A notable dichotomy exists between the bottom-up self-assembly paradigm used to create regular structures at the nanoscale, and top-down approaches used to fabricate arbitrary structures serially at larger scales. We have recently proposed an alternative approach based on dynamically programmable self-assembling materials, or programmable matter [1-3]. Unlike most current self-assembly methods, our approach uses dynamically-switchable affinities between assembling components facilitating the assembly of irregular structures. Here we present two experimental advances towards a programmable matter system: the development of a multi-chamber microfluidic chip for improved far-field assembly, and the demonstration of near-field inter-tile affinity switching using a thermorheological assembly fluid.

KEYWORDS: Self-assembly, programmable matter, switchable affinity, microtile

INTRODUCTION

Our programmable matter concept [1-3] (Figure 1), involves the assembly of components in a fluidic environment at two complementary levels: *far-field* and *near-field*. The far-field motion of the components is directed by modulating the fluid flow in the environment of the structure being assembled. The components themselves then control the near-field assembly by modulating the local fluid flow. Together, these effects allow the assembly of arbitrarily-specified, reconfigurable structures. The next two sections describe our recent experimental results addressing these two levels of assembly.

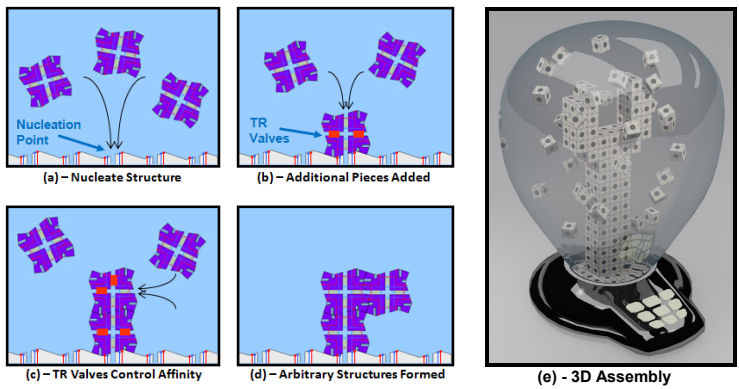


Figure 1. Programmable Matter Concept. (a) Far-field assembly: a free, unpowered component is attracted to a sink region on the active substrate. (b) Near-field assembly: component receives power to open and closing thermorheological valves to adjust local fluid flow and attract the next layer of components. (c-d) This process is repeated to build an arbitrary-shaped target structure. (e) Three-dimensional assembly in this manner is also possible.

978-0-9798064-1-4/μTAS2008/$20©2008CBMS

FAR-FIELD ASSEMBLY

We have previously demonstrated the far-field assembly concept in the assembly of plain silicon tiles [1] and latching silicon tiles [2] and have also studied the fluid dynamics of the process using simulations [3]. Our new microfluidic chip and the associated microtile shape are shown in Figure 2. The components are 12 µm thick regular hexagons with 100 µm sides, etched and released from the device layer of an SOI wafer. A number of channels attached to the main assembly chamber of the microfluidic chip act as sources or sinks to adjust the chamber's fluid flow field. The left chamber is used to select and store tiles prior to assembly. The right chamber is used to store tile sub-assemblies for hierarchical assembly. One of the main advantages of hierarchical assembly is that sub-assemblies can be fabricated in different assembly chambers in parallel, although the concept is demonstrated here with serial assembly. Figures 2b-g are images from assembly experiments conducted with this experimental system. Two- and three- component structures were assembled (Figure 2c-d) and tile latches were found to bond components together easily and effectively. Figures 2e-g are from hierarchical assembly experiments in which two assembled pairs were manipulated to form larger assemblies.

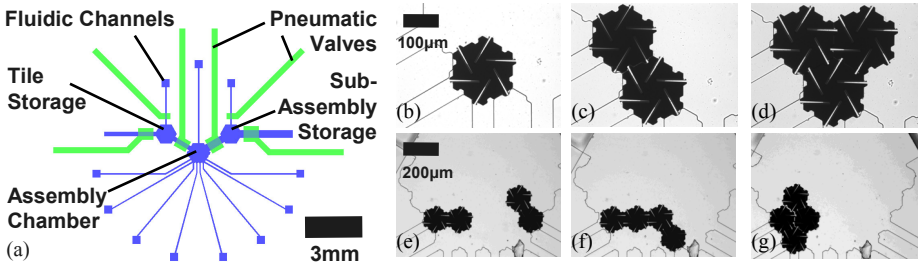
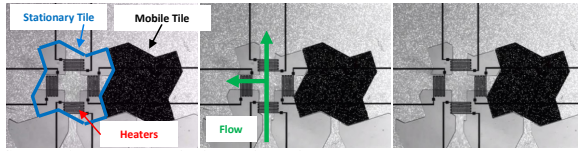


Figure 2. Multi-Chamber Microfluidic Assembly Chip and Assembly Component Designs (a) Multilayer PDMS chip design allows on-chip valving to isolate three separate chambers. The left chamber is used to select and store good quality tiles to be assembled in the main assembly chamber (centre). The right chamber is used to store sub-assemblies for hierarchical assembly. (b-d) Assembly of two- and three-component structures. (e-g) Hierarchical assembly experiments.

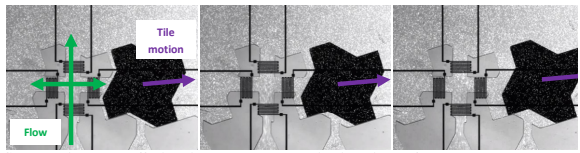
NEAR-FIELD ASSEMBLY

Our approach to dynamic affinity switching is based on the selective opening and closing of 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)$_x$ – poly(propylene oxide)$_y$ – poly (ethylene oxide)$_x$ triblock copolymer [4] that undergoes reversible sol-gel transition. Valves based on this polymer can be used to manipulate the location and strength of the external attraction basin around the tile and ultimately where the next tile is attached to the main structure, as shown in Figure 1. In order to study the use of the on-tile valves to dynamically tune affinities, we have patterned a "fixed tile" of PDMS with channels through it in a microfluidic chamber and a "mobile tile" made of silicon. The substrate has platinum heaters on it that are used to open and close the thermorheological valves. The valves have been characterized based on voltage required to stop the

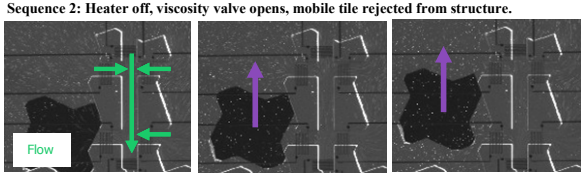
flow through the tile and have been used to locally attract and repel a silicon tile as shown in Figure 3.



Sequence 1: Heater on, mobile tile remains stationary.



Sequence 2: Heater off, viscosity valve opens, mobile tile rejected from structure.



Sequence 3: Heater on, mobile tile moves upwards

Figure 3. Assembly and disassembly of a mobile silicon tile from a fixed structure due to operation of thermorheological valves.

CONCLUSIONS

We have presented recent experiments aimed at addressing the near- and far-field assembly aspects of our programmable matter system. A multilayer microfluidic chip has been designed to demonstrate the use of far-field assembly to fabricate two- and three- tile structures from 100µm – sided hexagonal tiles. Concurrently, we have conducted near-field assembly experiments in which the local assembly around a tile is modulated by switching onboard valves on and off to redirect the local fluid flow. Together, these two sets of experiments represent significant advances towards our envisioned programmable matter system.

ACKNOWLEDGEMENTS

This work was supported by the National Science Foundation under Grant CMMI- 0634652 “Hierarchical Microfabrication: Actively Programmable Multilevel Fluidic Self-Assembly”. M. T. Tolley would also like to thank the Natural Sciences and Engineering Research Council of Canada for their support through the Postgraduate Scholarships program.

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