Presented at MERE 2016

Short, high-impact, large font title draws attention

Useful headers describe content of section

MITMECHE

Modular LEGO-based Microfluidics

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Some figures here don't have enough captions to understand – try to include at least a few words with each one

A large number of figures makes research intriguing.

A clear layout lets a visitor figure out what order to go from section to section (here organized in columns)

Make sure plots are large enough to read!

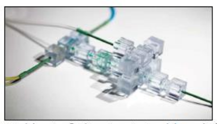
Text may be too dense in places

Simple schematics make it easier to describe key concepts

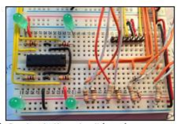
Introduction

Testing systems for blood and water analysis, research into fluid flow at the microscale, and chemical synthesis all depend heavily on microfluidic systems, which in turn rely heavily on cleanroom lithography and the significant infrastructure and training required. More accessible processes including inkjet toner, wax printing, and 3D printing typically lack high accuracy and feature resolution. Therefore, the need remains for a universal 'building block' approach for rapid prototyping of microfluidic devices.

We demonstrate a modular, low-cost microfluidic fabrication platform based on standard toy LEGO™ bricks. Channels and other features were machined on the brick surfaces. Each brick performs at least one operation on fluid, such as mixing, droplet generation, filtering, sample illumination, or microscope positioning. A variety of microfluidic systems can be generated by placing bricks in a series on a LEGO baseplate, and interfacing fluid inlet and outlet bricks with o-ring connections.



Modular microfluidic system via stereolithography [2]



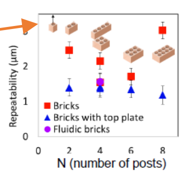
One inspiration: circuit boards

LEGO Bricks

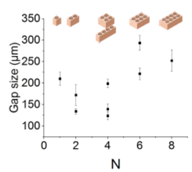
- Injection molded in mass quantities (52 million/day)
- Ubiquitous: Everyone in the world owns about 62 bricks on average
- Cost: 5-10¢

Repeatability

A modular part requires tight repeatability to ensure alignment and sealing between components.



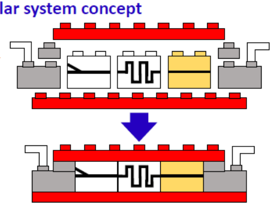
Repeatability trends for bricks shows an optimum for small-sized bricks.



Gap size between bricks varies in the microscale range.

→ Bricks have micron-scale repeatability, making them potential building blocks for modular microfluidics.

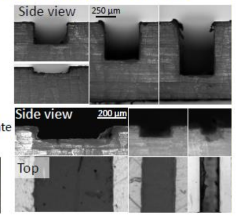
Modular system concept

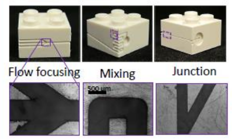


→ A modular system is assembled and reconfigured as needed.

Fabrication: Micromilling creates microscale features

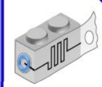
An endmill removes material from the brick surface. The Lego-based fixture ensures bricks are milled in the same state that they are used.



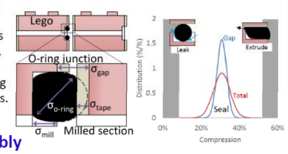


Milling cuts any programmed geometry with feature sizes 50-1500μm in depth and 175-1000μm in width.

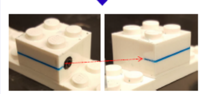
Sealing



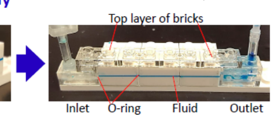
An adhesive film completes the fluid brick, and an O-ring enables sealing between bricks.



Assembly



Small O-rings compress between bricks, to reversibly seal.



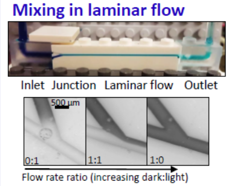
A system is built.

→ Components of a modular system are micromilled, and reversibly seal without additional hardware using an O-ring.

Basic flow manipulation

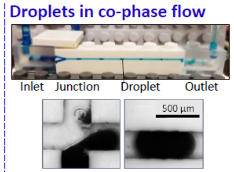
Controlled mixing, flow rate, and separation of fluids, and monitoring devices, are key microfluidic processes.

Mixing in laminar flow



Micrograph shows controlled laminar flow inside a brick system.

Droplets in co-phase flow

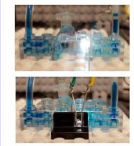


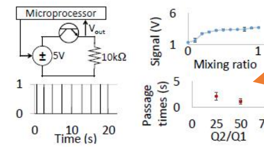
Mechanism of droplet formation depicted inside a brick with a 4-way junction.

→ Flow progresses as expected. Laminar flow and co-phase flow are both achieved.

In addition: Pressure drop is proportional to flow rate (not shown)
Droplet size is controlled by flow rate input
Capillary forces retain fluid inside disconnected bricks by design

Imaging





A light emitter/sensor pair digitally record the passage of fluid. This was used to monitor the generation rate and size of droplets and the extent of mixing of one colored and one clear fluid.

(Right) A smartphone camera lens attachment enables high-resolution recording of fluid flow.

→ Imaging systems are integrated around the fluid system.

Alternate fabrication methods: "Why don't you just use 3D printing?"

Brick type:	Milled fluidic brick		3D-printed brick (Form2)
Cost of materials	$0.12	<	$0.30-1.00
Time to produce	10 min	<	60 min
Repeatability	1-10μm	<	5-50μm
Dimensional variation	25μm	<	100μm
Interchangeability	30μm	<	130μm
Smallest enclosed channel depth	50μm	<	500μm
Roughness	0.04-1.2μm	<	4-50μm
Material	Polycarbonate	<	Proprietary, new resin

Conclusions

- We demonstrate that machined Lego bricks can be used as construction elements for modular microfluidics.
- Lego bricks are shown to have repeatability ~1-10μm.
- Milling enables design of a variety of fluid pathways, and sealing using adhesive tape and miniature O-rings provides robust sealing.
- Laminar flow and droplet generation demonstrate the usability of the bricks.
- Alternate fabrication methods were explored.
- Development of a library of functional bricks (including modified Legos and non-Lego elements), and additional materials and coatings, will expand the use of the system.

Acknowledgements

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References

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4. **Formation of bubbles and droplets in microfluidic systems**: Garstecki, Whitesides. 2005; 53(4).