Northumbria Research Link

ADVANCED 3D MORPHING TRANSDUCERS BY SMART HYDROGEL PATTERNING

Novelty/ Progress Claims

This paper demonstrates a unique way of creating heterogeneous layered structures of soft functional materials for advanced transducer applications. Hydrogel droplets with different composites were patterned by a "two-parallel plate" configuration used in microfluidics applications. Resulted heterogeneous layered structures of hydrogel were created, generating reconfigurable 3D (3-dimensional) deformation responding to discrete levels of stimulation inputs.

Background/ State of the Art

Morphing soft materials responding to external stimulation (e.g. electrical, mechanical and chemical) have promising applications in various fields, such as flexible electronics, biomedical transducers and soft robotics. One of the desirable developments is to make the self-shaping process controllable and programmable, at least for specific configurations.

Wang et al. [1] has demonstrated 3D shape control through planar (flat) patterned, homogeneous swell-able hydrogels. "Pre-designed" complex deformations were demonstrated by the periodically patterned hydrogel blocks made from multi-step lithographically. The shape morphing was then generated due to elastic mismatch between non-swelling substrate and swelling gel blocks [1, 2].

Whilst patterned homogenous layered structures can provide "pre-designed" 3D shapes, the post-swelling configurations are fixed. For reconfigurable morphing structures which dynamically change shapes responding to stimulation, heterogenous structures are desired.

Uniform heterogenous bio-content deposition was achieved previously by droplet microfluidics utilizing surface wettability (hydrophobic/philic patterns) [3]. More recently, using droplet microfluidics to control the formation of encoded multifunctional, and heterogeneous hydrogel building blocks have been exploited to form complex hydrogel architectures, inspired by natural bio-structures [4, 5].

Combining such latest development in smart hydrogel patterning, and the hydrogel-based 3D morphing technology brings the great potential of next generation re-configurable, stimuli-responsive, morphing soft transducers.

Description of the New Method or System

The state of the art of this work are demonstrated from the following two aspects:

- Heterogeneous hydrogel blocks patterned and layered by controlled surface wetting at hydrophobic and hydrophilic boundaries.
- Reconfigurable 3D morphing response to the stimulation inputs such as changing ionic concentration and temperature of the solution this hydrogel structure is immersed in.

The hydrogel used are Poly(Acrylamide-Sodium Acrylate), created from poly-acrylamide (PAAm) network with Sodium Acrylate (SA) which contains free positive sodium ions.

The gel swelling will happen when immersed in PBS (phosphate buffered saline) solution depending on ionic concentration of the gel and the solution (**Fig. 3**). Other stimulation such as temperature, electrical potential and physical constrains will all affect the swelling behaviour.

To structure and shape the hydrogel, hydrophobic/hydrophilic patterns were created. **Fig. 2** (top left) shows patterned Parylene-C® hydrophobic area (light green color) and hydrophilic silicon dioxide (SiO_2) patterns (dark green colored & square shaped), both on smooth silicon substrate.

Functional (swell-able) hydrogel droplets/blocks were deposited on this Parylene-SiO_2 surface, shape-controlled by hydrophobic/philic boundaries, and squeezed into "button" shape by non-functional soft substrate (e.g. non-swelling gel) before cross-linked to form the desired heterogeneous structure (illustrated in **Fig. 1** and pictured in **Fig. 2**).

Experimental Results

24-hour swelling ratio *ESR* and de-swelling ratio *DR* dynamically responding to PBS concentration and SA composition were obtained.

Initial reconfigurable gel deformation was achieved (flat shape – "S" shape – "C" shape). This responsive shape morphing demonstration was shown in **Fig. 4**. When immersed in PBS solution, the gel started bending. When the PBS concentrations changed (0.1M to 0.01M), the hydrogel structure re-shaped from "S" shape to "C" shape. This is a combined result from:

- Hydrogel block-B (pink colored) changes from de-swelling to swelling state, responding to the PBS concentration decrease;
- Hydrogel block-A (red colored) maintains high-ratio swelling.

More complex 3D morphing functions can be achieved with additional hydrogel functional blocks – to be carried out as near future work.

Word Count: 589

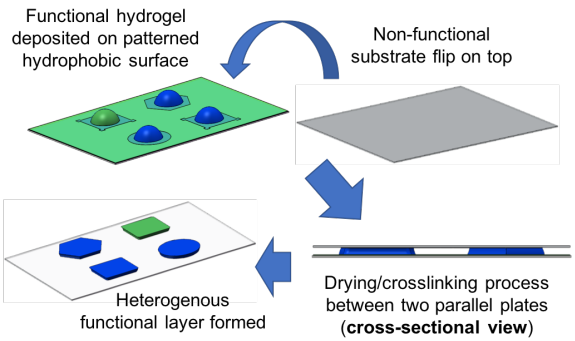

Figure. 1: Schematic view of the heterogenous hydrogel structure patterned by hydrophobic/philic surface.

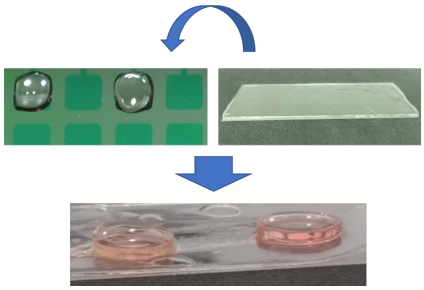

Figure 2: Photos showing two hydrogel blocks with different swelling behavior (different composites) assembled to non-swelling gel substrate.

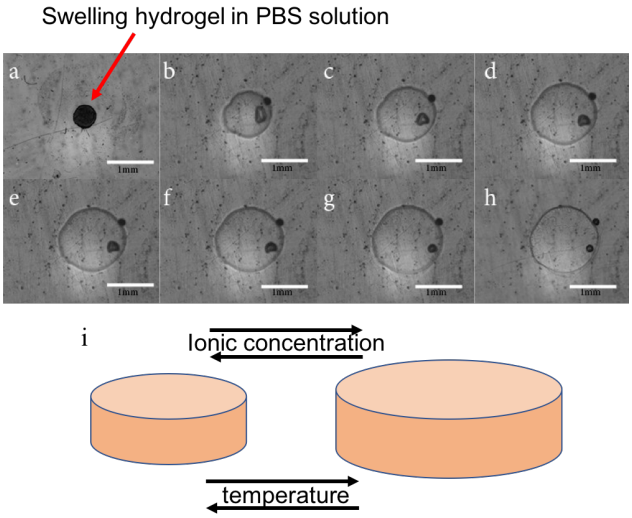

Figure 3: Microscopic photo shows PAAm-SA hydrogel swelling from (a) 0 min to (h) 10 minutes in 0.01M PBS solution. (i) The swelling hydrogel responds to ionic concentration variation and other stimulation such as temperature. Scale bar indicates 1mm.

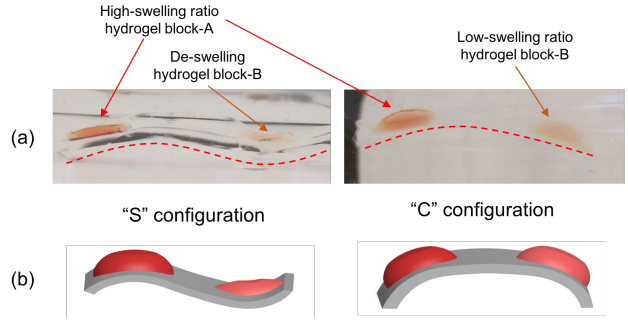

Figure 4: (a) microscopic photos; and (b) schematic illustration showing hydrogel structure shape reconfiguration from "S" shape to "C" shape.

REFERENCES:

[1] Z. Wang et al., "Site-Specific Pre-Swelling Directed Morphing Structures of Patterned Hydrogels", *Angew. Chem. Int. Ed.,* 56, 15974 – 15978, 2017

[2] Z. Wang et al., "Cooperative deformations of periodically patterned hydrogels", *Science Advances,* 3, e1700348, 2017

[3] Y. Li et al., "The application of fixed hydro-phobic patterns for confinement of aqueous solutions in proteomic microarrays", *Appl. Phys. Lett.,* 99, 073703, 2011

[4] M-Y. Chiang et al., "Constructing 3D heterogeneous hydrogels from electrically manipulated prepolymer droplets and crosslinked microgels", *Science Advances,* 2, e1600964, 2016

[5] X. Ji et al., "Encoding, reading, and transforming information using multi-fluorescent supra-molecular polymeric hydrogels", *Advanced Materials,* 30, 1705480, 2018