**ABSTRACT**

Using a thin, layered elastomeric materials, we can create a pattern of surface with crack and fold hybrid structures. This system can be applicable as hybrid microfluidic system with open (crack) and closed (fold) channels. UV/ozone-exposed bilayer of the materials was fabricated into the guided fold structures, as a closed channel. For an open channel, the prepatterned mechanical notch on the material surface to form the crack, by addressing the site of stress concentration. This hybrid system consequently offer a new method as an bio-inspired fluidic network for water retention.

**KEYWORDS:** Crack, Fold, Bio-inspired, Microfluidic system, Stress concentration

**INTRODUCTION**

Water harvesting lizards living in desert have remarkable ability to collect and transport water through their skin to the mouth. The lizards drink water using specialized scaled integuments, semi-tubular capillary system, which consists of honeycomb-like scales as water reservoir, and interscalar channels as water transporter [1]. Inspired from these unique integuments, we suggest that two main components of the lizard’s semi-tubular capillary system can be a major components of microfluidic systems: the scales as an open channel and the interscalar channel as a closed channel. Thus, we utilized a novel controlled crack-fold technique to fabricate open-closed channels in microfluidic system.

Thin, layered elastomeric materials forms periodic surface pattern in response to imposed constraints, such as wrinkle and fold structure [2]. Cracks, however, generally cause materials failure of devices or structures, thus they are considered as undesirable phenomenon. Although cracks are typically difficult to control precisely due to their randomness, crack formation can recently be controlled under the delicate conditions, such as the mechanical, geometrical and loading parameters [3, 4].

**EXPERIMENTAL**

![Figure 1](image) (A) Strategies to fabricate a bio-inspired crack-fold hybrid microfluidic system, inspired from water harvesting lizards in the desert. The scales considered as an open channel and the interscalar channel as a closed channel. Open channel was fabricated with controlled crack formation, and closed channel with guided fold formation. (B) Fabrication process for controlled crack formation. With prepatterned elastomer, the thin, stiff layer was formed with UV/O treatment in the prestretched condition. When the prestrain is released, the crack-fold structure is spontaneously formed. (C) Simulated results for stress distribution at the prepatterned notch according to prestrained conditions. The tensile stress indicates red, while the compressive stress blue, relatively.
Using prepatterning process before fabrication described in Figure 1B, the stress distribution can be controlled throughout the surface at the predefined position. We simulated the prepatterned surfaces using finite element model. When we increased the extent of the strain, more tensile stress were concentrated at the notch, while there were compressive stress at the line-patterned foundation (Figure 1C). From this results, we suggested that the focused tensile stress at notch might result in crack formation, while compressive stress at foundation might form the fold structure.

RESULTS AND DISCUSSION

As expected, cracks were created from the predefined notches as initiating points. When the extent of tensile strain became increased, the number of cracks formation was also increased. At the 75% of prestretched condition, the cracks were formed completely at almost of prepatterned notches (Figure 2A). Simultaneously, the surfaces were guided to be folded due to the condition of compressive stress as simulated. Their fold periodicity became shorter and stabilized when the strain became increased (Figure 2B). From these results, we suggested that the controlled crack and fold was successfully fabricated from the initiating notches and guiding line under the prestrained condition.

![Figure 2. Fabrication of controlled crack. SEM images for controlled crack (A) and fold (B) according to pre-stretched conditions (0, 45, 60, and 75%). (A) The formation of crack was controlled according to the extent of strain. At the 75% prestretched condition, the crack was created completely throughout the overall surface. (B) The surface was folded into shorter wavelength, as the prestretched strain increases.](image)

To evaluate the performance of a hybrid microfluidic system, the fluorescent dye was introduced to visualize the surfaces of system (Figure 3). The dye was firstly retained on the crack induced open channels. Subsequently, the dye was absorbed into folded closed channels by the capillary force. For the strains from 45% to 60%, interestingly, there was only dye absorption into folded channels starting from the crack. Red signals were detected over all of the folded channels at 75% prestretch due to complete crack formation. We collectively concluded that this system can be applicable to control the fluid flow.
Figure 3. Water retention ability of crack-fold hybrid microfluidic system according to the extent of prestretched strain. (A) Schematic view of water retention in microfluidic system with open (crack) and closed (fold) channel. (B) Phase images of patterned surface and fluorescent images of retained water (Gray: phase, Red: rhodamine B).

CONCLUSION
We have presented a simple, but highly reproducible technique to generate controlled cracks by simply varying the prestrained condition of prepattened elastomer with mechanical notches. Active tuning of a controlled pattern-formed elastomer collectively enables to fabricate a cross-networked microfluidic system with open/closed channels.

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