Supplementary Material: Swelling-induced Patterning in Soft Microchannels

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A: MANUFACTURING SOFT MICROCHANNELS

Fig. 1 illustrates the four steps involved in the fabrication of our soft microchannels:

(a) We create the base of the microchannel using a brass mould that is machined by micromilling with resolution of 5 μm (Datron). The mould is filled with Sylgard 184 (Dow), a heat-curable silicone elastomer, prepared by mixing the monomer base and the curing agent in a 10:1 weight ratio, before degassing it in a vacuum desiccator for 10 min. This PDMS elastomer is then carefully poured into the mould to avoid trapping air bubbles, and heat-cured in an oven at 85 °C for 45 mins. By the end of this step, the PDMS is only partially cured, so that it can be bonded onto the PDMS membrane, see (c).

(b) In parallel with (a), we produce the thin PDMS membrane that will act as the soft boundary for the microchannel. This is done by first spin-coating (POLOS SPIN150i) PDMS films onto a cleaned Polymethyl Methacrylate (PMMA) Perspex plate (Policril Acrylic, Irpen S.A.U, UK) at 1000 rpm for 310 s to achieve a membrane thickness of 26.98 ± 0.16 μm. The film is then partially cured in the oven at 85 °C for 15 mins.

(c) The partially cured PDMS base created in step (a) is taken out of the brass mould. The corners of the structure are cut off to remove curved parts of the PDMS surface formed by capillary effects. Small holes are created as inlets and/or outlets for the working fluids. The channel base is then flipped and bonded onto the PDMS membrane which is still attached to the Perspex plate. The compound structure is placed in the oven at 85 °C for another three hours until the PDMS is fully cured and the membrane is bonded to the base.

(d) Once the PDMS base of the microchannel and the PDMS membrane are fully cured and closely bonded, we cool them at room temperature (21 °C) for one hour before detaching the microchannel from the Perspex plate.

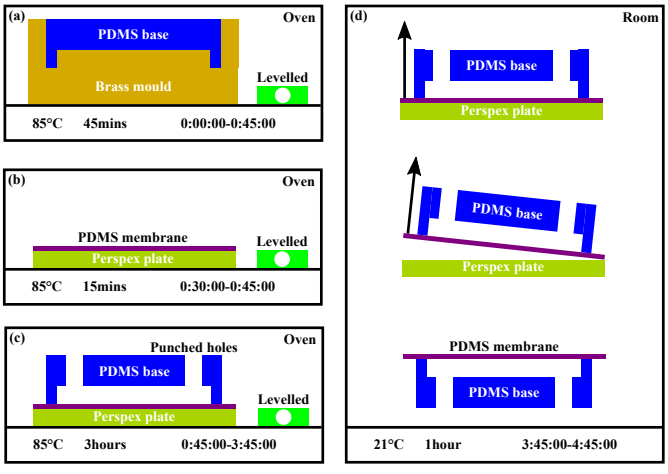

FIG. 1: Schematic diagram of the fours steps (a-d) involved in the fabrication of our soft microchannel.

B: MEASURING YOUNG'S MODULUS

In order to measure the Young's modulus of the PDMS, we produced cylinders of height $h_0 = 10.1 \pm 0.06$ mm and diameter $D_0 = 12.85 \pm 0.06$ mm from the same PDMS (Sylgard 184 silicone elastomer) described in section A. These cylinders were then compressed in an Instron 3345 machine (Instron, USA) with a 1 kN load cell and resolution better than 0.05 N, by applying the compression at a rate of 0.01 mm/s, and recording the corresponding applied force F and the level of the samples' compression δh. This allowed us to measure the the engineering stress $\sigma_{en} = F/(\pi D_0^2/4)$ and the engineering strain $\epsilon_{en} = \delta h/h_0$, respectively. The typical experimentally measured stress-strain curves are shown in Fig. 2. Assuming that the only non-zero component of the Cauchy stress is in the direction of the compression, we can use the relationship between the engineering strain and stress for an incompressible Mooney-Rivlin material

$$\sigma_{en} = 2\left(\lambda - \frac{1}{\lambda^2}\right)\left(C_1 + \frac{C_2}{\lambda}\right), \qquad (1)$$

where $\lambda = 1 - \epsilon_{en}$, to find the Young's modulus of the PDMS, since in the limit of small deformations (i.e. when $\lambda \to 1$):

$$E = \lim_{\lambda \to 1} \frac{d\sigma_{en}}{d\lambda} = \lim_{\epsilon_{en} \to 0} \frac{d\sigma_{en}}{d\epsilon_{en}} = -6(C_1 + C_2). \qquad (2)$$

When fitting (1) to the experimental data as shown in Fig. 2, we obtained $E = 1.99 \pm 0.04$ MPa.

The same experimental procedure was then repeated with the cylinders once they were fully swollen in a 20 cSt silicone oil, yielding a Young's modulus of $E = 1.94 \pm 0.01$ MPa after swelling. This very modest change in the Young's modulus during swelling is consistent with the literature on swelling [1]. Given the modest change in the Young's modulus, we assumed it to be constant in our numerical model presented in the main article.

C: MEASURING SWELLING RATIO

We studied the swelling properties of the PDMS sheet by immersing membrane samples fabricated by the procedure described in section A in the 20 cSt silicone oil that we used to induce swelling in our main experiment. The spin-coated PDMS membranes were cut into multiple squares of area $S_0 \approx 10 \times 10$ mm^2 before they were peeled off

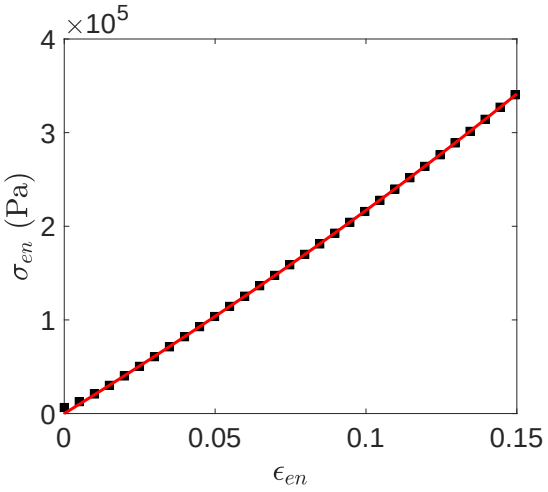

FIG. 2: Typical stress-strain curve for an uni-axially compressed PDMS cylinder measured experimentally (black dots) and predicted by the Mooney-Rivlin model (red line). This compression test was repeated 17 times using three different cylindrical samples to obtain the averaged Young's modulus $E = 1.99 \pm 0.04$ MPa.

the substrate, and floated in a petri dish filled with the silicone oil. The change in their area due to swelling was recorded for 5 minutes by a top-view CMOS camera (Teledyne Dalsa CR-GM00-H1400, resolution 1400 × 1024 pixels) at 10 frames per second. The time evolution of the swelling ratio is then obtained from the square root of the area variation i.e. $C(t) = \sqrt{S_t/S_0} - 1$, where S_t is the area of the PDMS membrane at time t. The corresponding data averaged over several experiments is shown in Fig. 1 (d) of the main article. The experimental data is well fitted by an exponentially decaying function, i.e. Eq. (1) in the main article, from which we can predict the equilibrium swelling ratio to be $C_{eq} = 0.152 \pm 0.008$.

[1] T. Sakai, M. Kurakazu, Y. Akagi, M. Shibayama, and U. Chung, Effect of swelling and deswelling on the elasticity of polymer networks in the dilute to semi-dilute region, Soft Matter **8**, 2730 (2012).