Supplementary Information

Aerosol-Jet Printed Conformable Microfluidic Force Sensors

Qingshen Jing, 1 Alizée Pace, 1 Liam Ives, 1 Anke Husmann, 1 Nordin Ćatić, 1 Vikas Khanduja, 2 Jehangir Cama, 3,4,5* and Sohini Kar-Narayan 1,*

1Department of Materials Science and Metallurgy, University of Cambridge, 27 Charles Babbage Road, Cambridge CB3 0FS, UK.
2Cambridge Young Adult Hip Service, Addenbrooke’s - Cambridge University Hospitals, Box 37, Hills Road, Cambridge CB2 0QQ.
3Cavendish Laboratory, University of Cambridge, JJ Thomson Avenue, Cambridge CB3 0HE, UK.
4Living Systems Institute, University of Exeter, Stocker Road, Exeter EX4 4QD, UK.
5College of Engineering, Mathematics and Physical Sciences, Harrison Building, University of Exeter, North Park Road, Exeter EX4 4QF, UK

Correspondence: sk568@cam.ac.uk, j.cama@exeter.ac.uk

The following supplementary information is provided for this work:

Note N1
Figure S1-S8
Movie M1
Note N1:
Epoxy (Loctite 9483) and silicone-based glues (PDMS, Dowsil 3140, Dowsil 732) were tested for bonding the PDMS to the Kapton film. Bonding strength was examined based on whether or not there was liquid leakage from the device on the application of external forces. The results are summarized in the table below. Most adhesives were either good for Kapton or PDMS but not for both. We finally chose to use a primer (Dowsil 1200) on the surface of Kapton to increase the adhesion between Dowsil 3140 silicone glue and Kapton, which achieved a good sealing result.

| Glue type                        | Attachment to Kapton | Attachment to PDMS | Note                                      |
|----------------------------------|----------------------|--------------------|-------------------------------------------|
| Uncured PDMS (SYLGARD 184)      | No                   | Yes                |                                           |
| Epoxy (Loctite 9483)            | Yes                  | No                 |                                           |
| DOWSIL 3140                     | No                   | Yes                |                                           |
| DOWSIL 732                      | Yes                  | Yes                | Non-flowable but good strength            |
| 732 mixed with PDMS (Uncured)   | Yes                  | Yes                | Flowable with slightly reduced strength from 732 |
| DOWSIL 1200 Primer + 3140       | Yes                  | Yes                | Strong bonding yet need two steps to apply the glues |
Figure S1: AutoCAD designs of the NaCl mold. Each mold was printed with multiple layers of three different patterns, from the bottom to the top shown in this figure. Red lines represent the printing paths.
Figure S2: Hysteresis measurement of the capacitance from a representative force sensor when being compressed and released, for 2 continuous rounds. The combination of this measurement and stability demonstrated in section 2.6 together show negligible hysteresis effect of the sensor.
Figure S3: Capacitance values from the force sensor under continuous compression at several forces for up to 120 s. No drift in the capacitance was observed within these timescales.
Figure S4: The force sensor’s temperature response showed an increase in the initial value of the capacitance with increasing temperature. However, the sensitivity remains similar within this temperature range, and hence the temperature factor can be accounted for by simply zeroing out the shift in the absence of any applied force.
Figure S5: Illustrations of the comparisons in design between parallel electrodes and interdigitated electrodes. The electrodes are shown in blue.
Figure S6: Illustrations of comparisons between microfluidic channels with different widths. By putting the same amount of liquid into each channel, the coverage areas of electrodes for the ‘narrower’ and the ‘same width’ channel are similar while this value is smaller in the ‘wider’ channel. However, the narrower the channels, the faster the liquid reaches the end of the channels, which diminishes its measurement range.
Figure S7: A simulation study of the reservoir’s behaviour under a bending curvature, which shows a slight effect on the sensitivity of the sensor.
Figure S8: Capacitance values of the force sensors recorded when triggering a robotic clamp. Green dotted lines show the thresholds where, when the capacitance value falls into a certain region, the claws are triggered to act in a defined manner.
Movie M1. (Attached as a video file.) The sensor was attached to the outer circumference of the curved wall of a plastic petri dish to detect the force the operator applied to squeeze the petri dish. The robotic claw was programmed to mirror the operator’s action based on the force detected from the sensor.