Electronic Supplementary Material (ESI) for Journal of Materials Chemistry C.

Supplementary Information

Microfluidic capacitive sensors with ionic liquid electrodes and CNT/PDMS nanocomposites for simultaneous sensing of pressure and temperature

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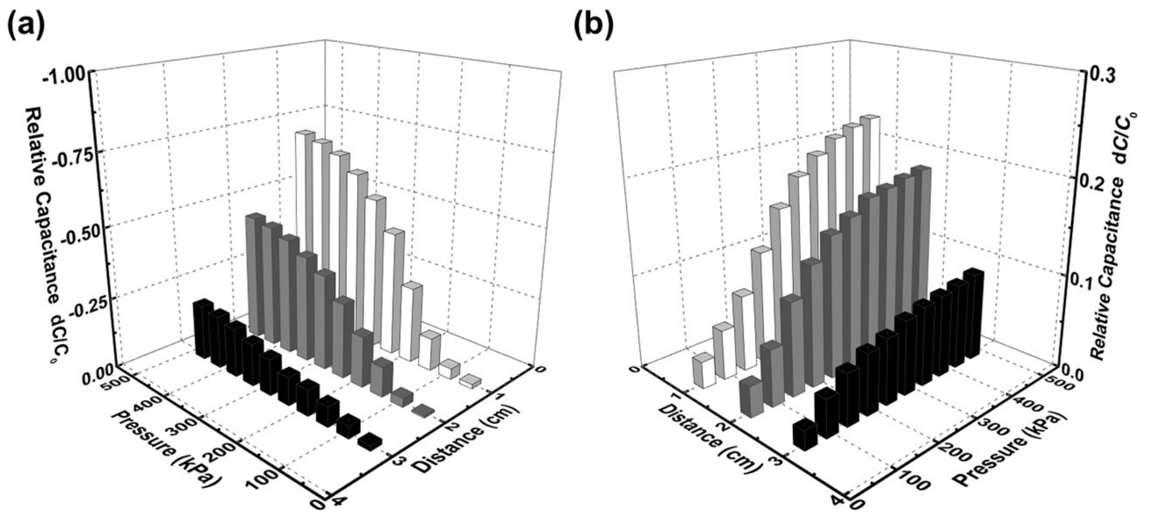

Figure S1. Relative capacitance changes as a function of applied pressure at different positions from the electrodes for the microfluidic capacitive sensors with (a) 2 and (b) 4 wt% CNTs.

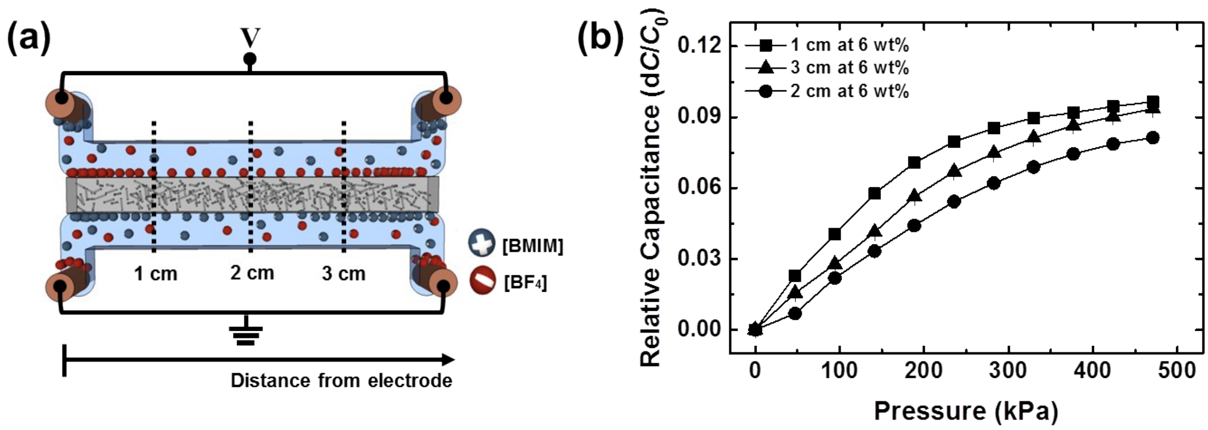

Figure S2. (a) Schematic illustration of the ion distribution in the microfluidic capacitive sensors with connecting the copper wire electrodes on both sides of the microchannels. (b) Relative capacitance changes as a function of applied pressure at different distances from the electrodes for the microfluidic capacitive sensor with a CNT concentration of 6 wt%.

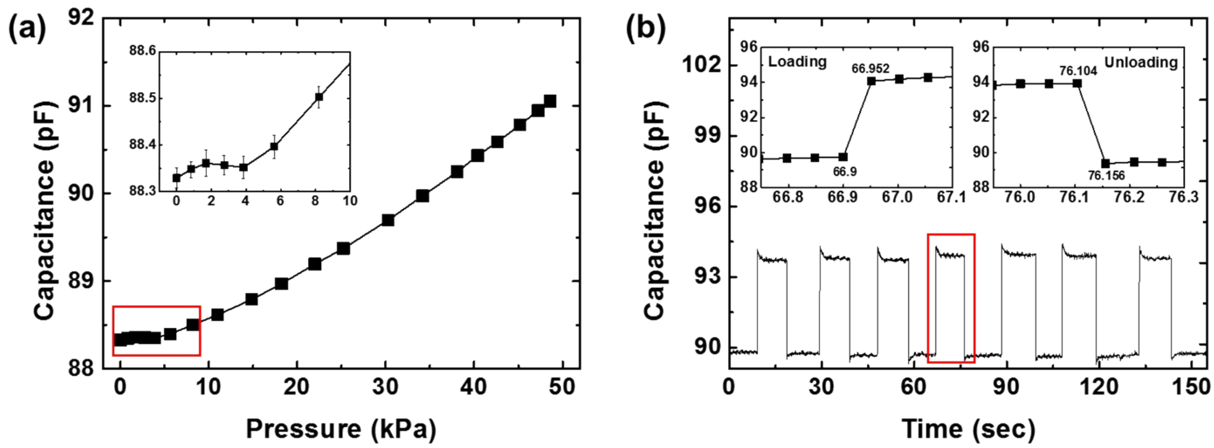

Figure S3. (a) Capacitance profiles of microfluidic capacitive sensors with 6 wt% CNTs as a function of applied pressure at a range of 0–50 kPa. (b) Capacitance changes of microfluidic capacitive sensors with 6 wt% CNTs as a function of time with cyclic loads/unloads of the vertical pressure of 60 kPa. The insets in Figure S3b show the response time of microfluidic capacitive sensors at both loading and unloading cycles. The pressure applying position of both tests was 1 cm from the wire electrodes.

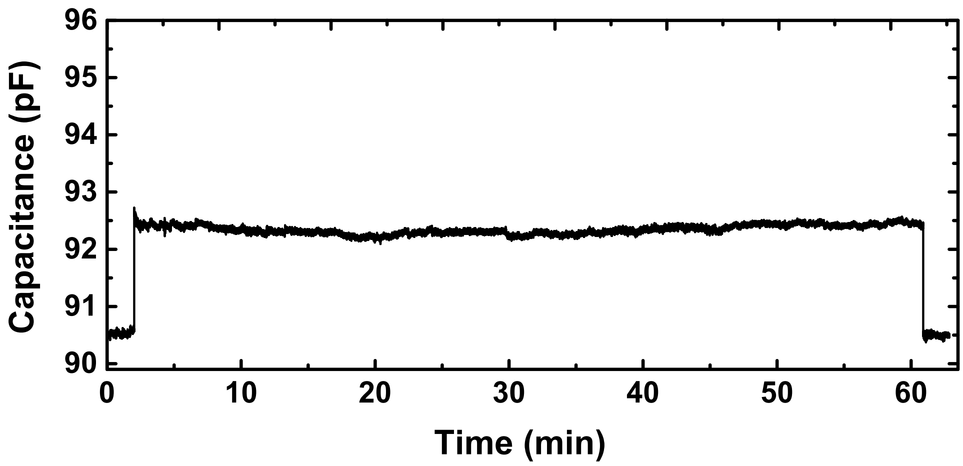

Figure S4. Capacitance change of the microfluidic capacitive sensor as a function of time. A constant force of 1N was applied for 60 min at a position of 1cm from the wire electrode. The sensor was fabricated with 6 wt% CNTs and the capacitance was measured under the constant AC voltage (1 V, 1 kHz).

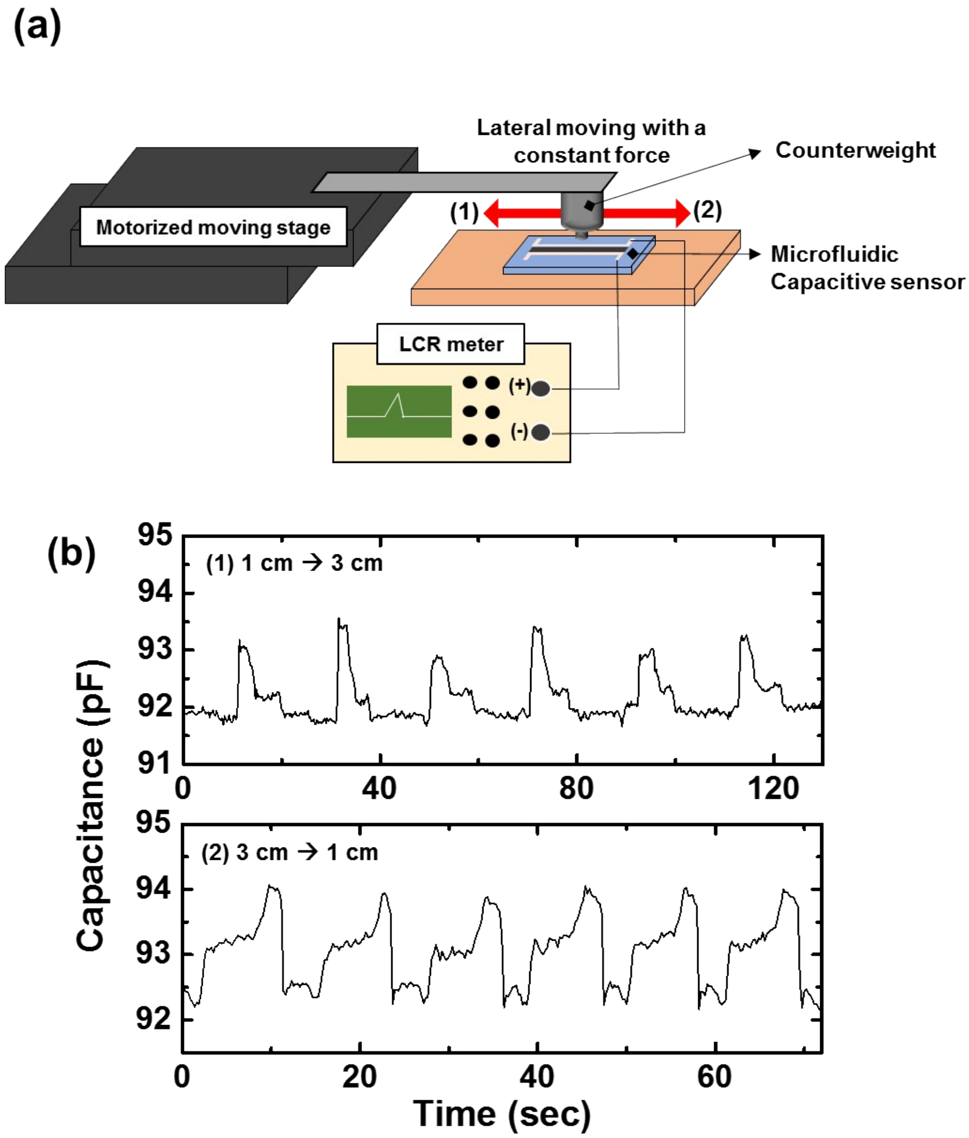

Figure S5. (a) Schematic illustration of the lateral movement of constant force along the sensing element of our microfluidic capacitive sensor with a motorized moving stage. Laterally movable motorized stage was connected with a counterweight (50 g) and the counterweight was able to move backward or forward directions with applying a constant force of 0.5 N onto the microfluidic capacitive sensor. A moving speed of the counterweight was 2.941 mm/s. (b) Capacitance changes of the microfluidic capacitive sensors subjected to repetitive motions of the counterweight at different sliding modes. The experiments were performed with the microfluidic capacitive sensor with 6 wt% CNTs.

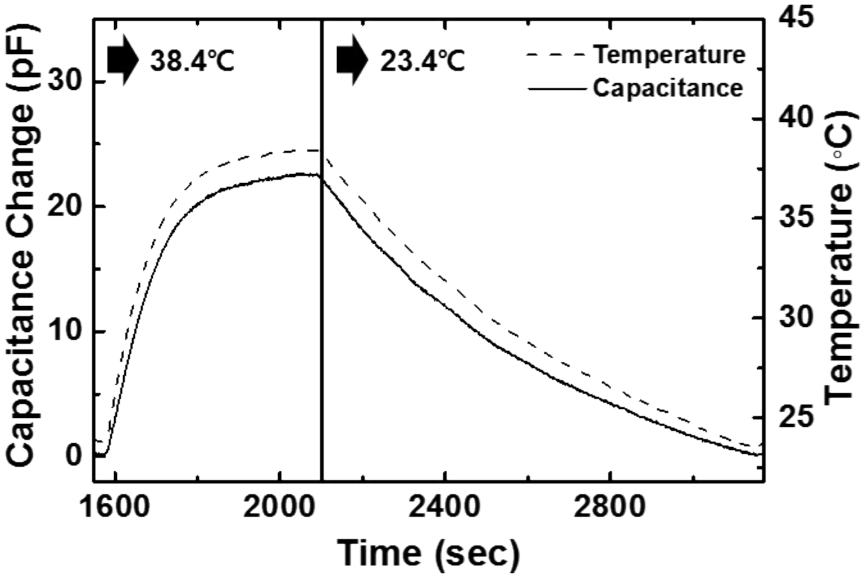

Figure S6. Magnification of the 2nd peak in Figure 5c. The graph shows the capacitance changes in response to the temperature changes (23.4–38.4°C)

Table S1. Comparison of the performance of liquid-typed pressure sensors including microfluidic capacitive sensors used in this study

Reference	Types of transduction	Active Materials	Response time	Minimum detection	Maximum detection	Sensitivity
Sun et al. [Ref. 27]	Capacitive type	Hydrogel / NaCl	-	-	40 kPa	0.011 kPa^{-1}
Roberts et al. [Ref. 28]	Capacitive type	EGaIn	-	2.5 kPa	25 kPa	0.052 kPa^{-1}
Hotta et al. [Ref. 38]	Capacitive type	DI water	-	12.5 kPa	300 kPa	4.5×10^{-5} pF kPa^{-1}
Li et al. [Ref. 39]	Resistive type	Ethylene glycol	< 2.5 ms	~70 Pa	1800 kPa	8.4×10^{-5} – 0.45 kPa^{-1}
Liao et al. [Ref. 40]	Capacitive type	Polyalcohol, water and silicon oil	-	0.05 N	1.05 N	3.51 pF N^{-1}
This work	Capacitive type	CPCs / Ionic liquid	<52 ms	4 kPa	500 kPa	-4.02×10^{-3} kPa^{-1} (1 wt% CNTs) 1.10×10^{-3} kPa^{-1} (6 wt% CNTs)

Our microfluidic sensor systems have advantages such as the detection capability of lateral pressure movement, bimodal signal, and high sensitivity to temperature changes. Although our sensor systems showed the comparable pressure sensitivity to other liquid-type pressure sensors at high pressure range (100 – 300 kPa) as shown in Table S1, the pressure sensitivity of our sensors at low pressure range need to be improved. In addition, leakage of ionic liquids and wire electrode connection could be additional problems of our microfluidic sensor for its practical usage. However, such problems of our current microfluidic capacitive sensor systems can be solved by using ion-gel based capacitive sensor systems. The results of the ion-gel based capacitive sensors will be published in near future elsewhere.

Table S2. Comparison of the performance of several studies in temperature sensing devices including microfluidic capacitive sensors used in this study

References	Types of transduction	Active materials	Minimum detection	Sensitivity
Kim et al. [Ref. 11]	Resistive type	CNT microyarns	-	0.24% $^{o}C^{-1}$
Honda et al. [Ref. 14]	Resistive type	CNT / PEDOT:PSS composite	-	0.61% $^{o}C^{-1}$
Trung et al. [Ref. 15]	Transistor type	R-GO / PU nanocomposite	0.2 ºC	1.34% $^{o}C^{-1}$
Yeo et al. [Ref. 16]	Resistive Type	Ti / Pt strip	-	1.43 Ω $^{o}C^{-1}$
Ota et al. [Ref. 30]	Resistive and Capacitive type	EGaIn and Ionic liquid	0.64 ºC	3.9% $^{o}C^{-1}$
This work	Capacitive type	CPCs / Ionic liquid (6 wt% CNTs)	0.5 ºC	3.46% $^{o}C^{-1}$ (1.78 pF $^{o}C^{-1}$)