Soft Matter

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Electro-Mechanical Actuator with Muscle Memory

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Electronic Supplementary Information (ESI):

The shape memory effect was characterized for different strains between 20 and 150 % for a programming temperature of 100ºC.The fixity/recovery rates of the material are reported in Figure S1.

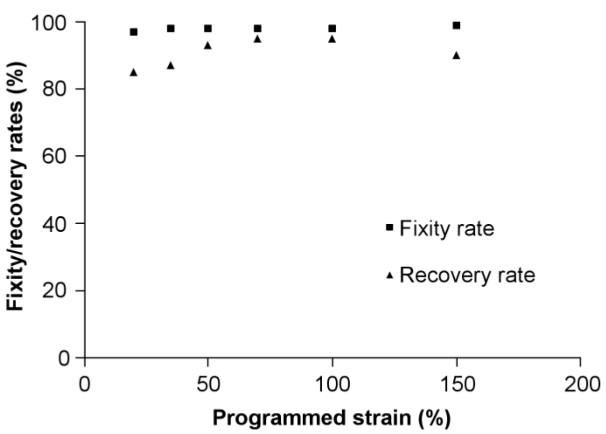

Figure S1: Shape memory properties of IPMC for programmed strain between 20 and 150%.

The fixity rate (R_f) of the EMM material is high, between 98 and 99 % for all programmed strain indicating that the ability to set a shape of the material is excellent and similar to the previously reported rate for pure Nafion.[1,2] The ability to fix one or several shapes at different temperatures and at strain between 20 and 100 % is useful to create different EMM materials.

Figure S2 shows a schematic view of electrical actuation measurement with a laser sensor.

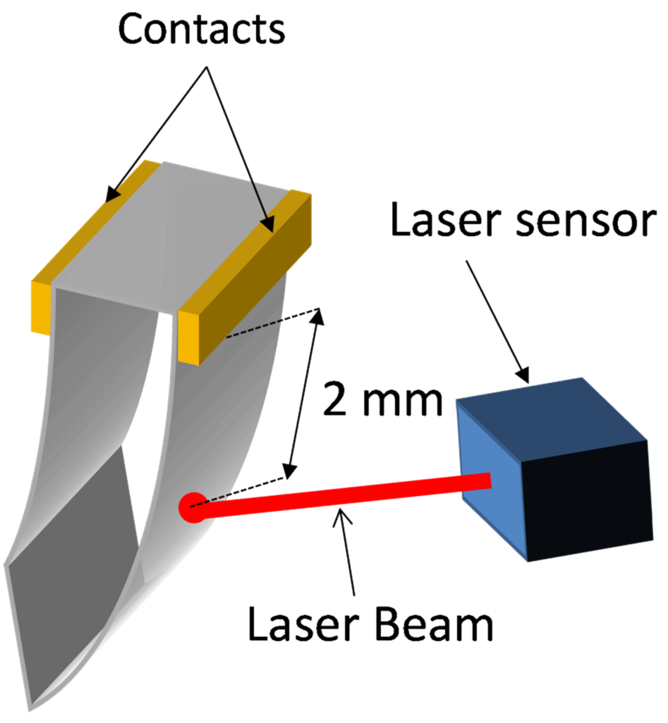

Figure S2: Schematic view of bending electrical actuation tip displacement measurement.

Figure S3 shows the voltage and the current consumption of one EMM actuator without programming for a frequency of 0.5 Hz. The displacement amplitude at 2 mm from the contact clamp is 41 µm. The same measurements were performed for actuators in the different programmed strain.

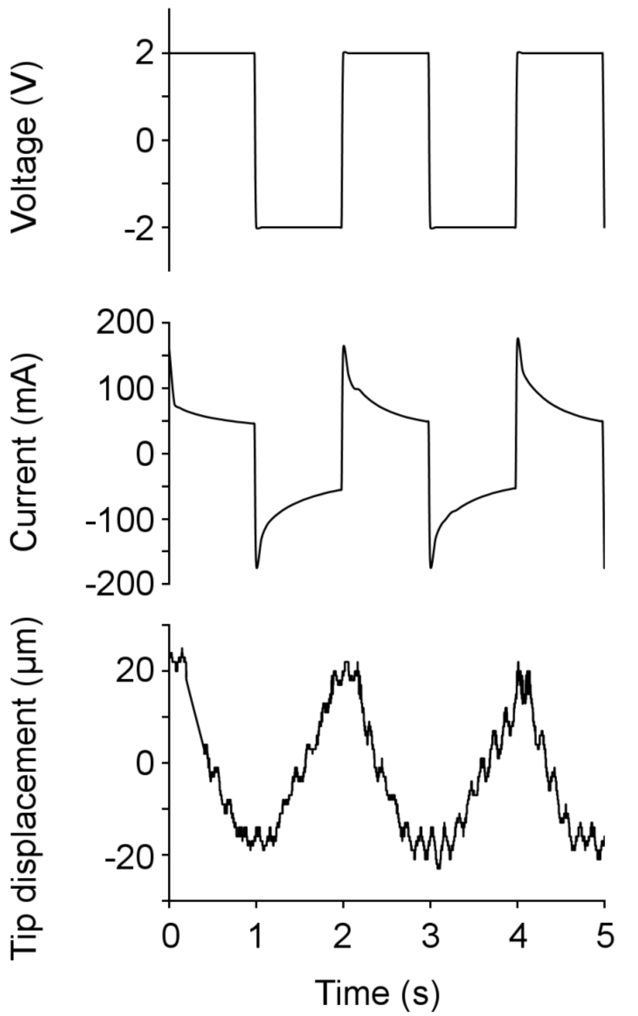

Figure S3: Voltage applied to the sample, electric current response and tip displacement vs. time of one electrical actuator without programming

Figure S4 presents the multi temperature shape memory capability for the EMM material.

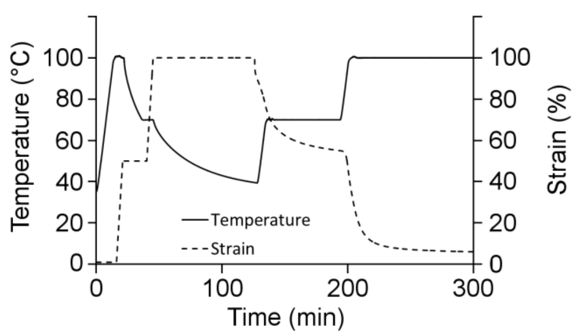

Figure S4: Strain controlled multi-temperature shape memory cycle (programming and recovery)

The EMM material is capable of memorizing two different shapes with strain increments as high as 50% each for two different temperatures (70 and 100°C on Fig. S4). It is also able to recover individually the different shapes at their programmed temperature. This allowed introducing several “memories” in IPMC artificial muscles.

Figure S5 shows the cracking process which happens during the programming of materials. The stretching is roughly in the same direction as the scratching, and the cracks in the electrodes appear perpendicular to the grooves (Fig. S5). This process explains the conductivity variation of the metals electrodes leading to difference response in actuation for an applied potential of ±2V.

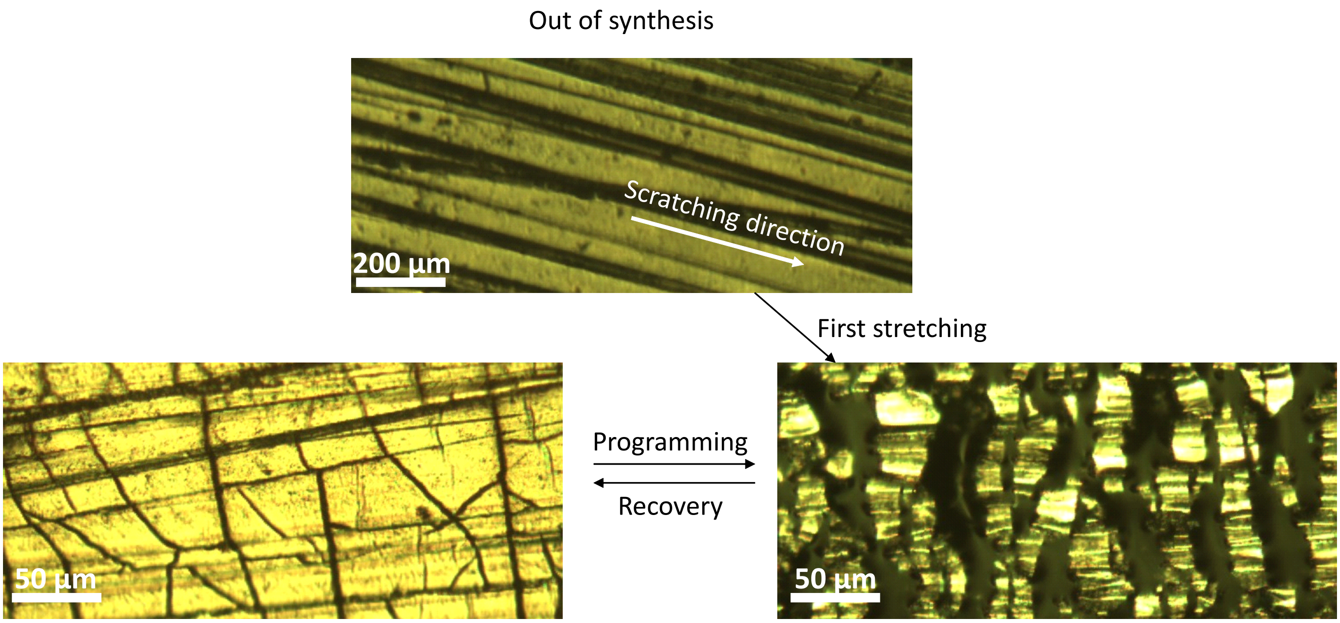

Figure S5: Cracking process of platinium electrodes.
The original conductance (0.125 Ω^{-1}) decrease to 3.5×10^{-4} Ω^{-1} when the material is programmed to 70 % strain and drop down below 5×10^{-7} Ω^{-1} for a programming at 100%. For a 50 % programmed sample the conductance is increase from 4.4×10^{-3} to 0.1 Ω^{-1} under shape recovery.

Supplementary Video 1: The supplementary video shows three actuation states of the EMM material under square wave potential of ± 2 V at a frequency of 0.25 Hz. The first programmed state shows the EMM material stretched at 100% strain, achieved by 50% stretching at 90 °C and 50% stretching at 70 °C. It is unable to actuate electrically though voltage is being applied as in later frames. After exposure to 70 °C, 50% of the programmed strain is reversed and the bending actuation is partially restored. After exposure to 90 °C, the original EMM material shape is recovered and the original bending actuation is fully restored.

References:

1. T. Xie, *Nature*, 2010, **464**, 267–70.
2. T. Xie, K. A. Page, and S. A. Eastman, *Adv. Funct. Mater.*, 2011, **21**, 2057–2066.

