Ionic skin

Jeong-Yun Sun, Christoph Keplinger, George M. Whitesides, and Zhigang Suo**

Supplementary Video 1. A sensor detects the bending of a finger.

We attached a sensor to a finger, and used two metallic wires to connect the sensor to a capacitance meter. When the finger bent, the capacitance meter indicated the increase of the capacitance of the sensor, and the watch indicated the time. As the finger bent repeatedly, the sensor remained transparent, and conformed to the movement of the joint.

Supplementary Video 2. An equibiaxial stretcher.

We designed and fabricated a device to pull a thin sheet equibiaxially.

Supplementary Video 3. An ionic skin detects the location of touch.

We attached an ionic skin containing four sensors to the back of a hand, and used a rotational switch to connect a capacitance meter to the sensors one at a time. The capacitance was recorded through a Labview (National Instruments) program, and the capacitance of the connected sensor was displayed on the screen of a laptop as a function of time. When the capacitance meter connected to a specific sensor, the capacitance took a baseline value before a finger pressed the sensor, increased to a high value when the finger pressed, and returned to the baseline value after the finger was removed from the sensor. The baseline values of the four sensors were different because the sensors had hydrogel interconnects of different lengths.

Supplementary Video 4. An ionic skin detects the pressure of touch.

We connected the capacitance meter to a specific sensor. When a finger applied several levels of pressure on the sensor, the capacitance of the sensor changed.

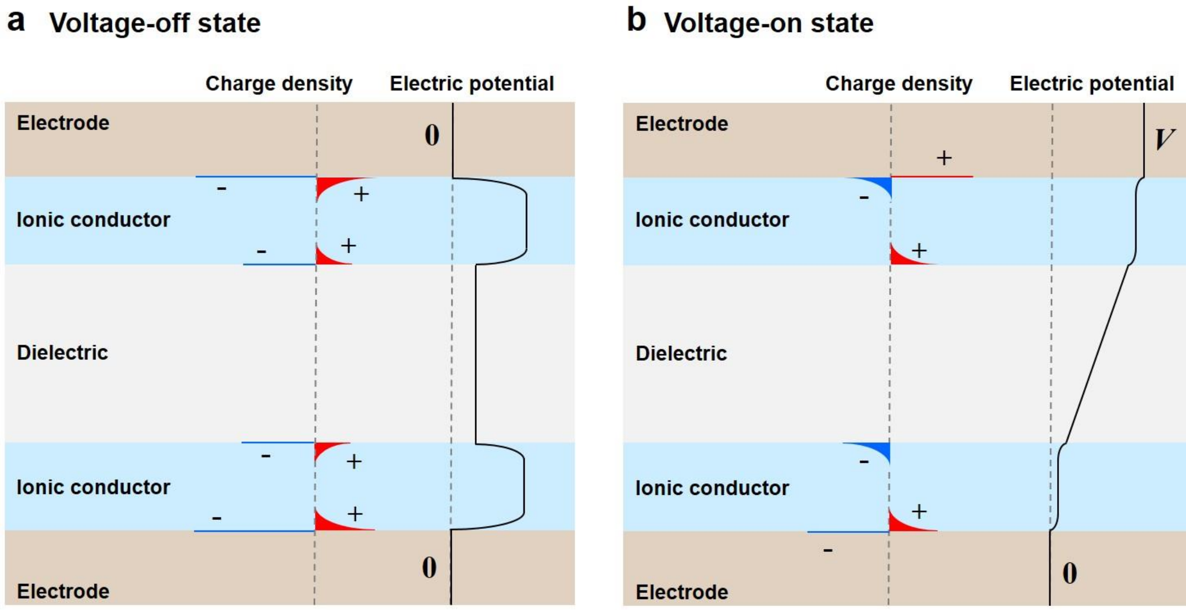

Figure S1 | Distributions of electric charge and potential across the structure. (a) In the voltage-off state, the two electrodes are grounded, and the distributions of charge density and electric potential are symmetric with respect to the centerline of the dielectric. Trapped electrons and adsorbed ions may localize within molecular distance from the interface between a metallic electrode and an ionic conductor. This localized layer has a net electric charge; the net amount and the polarity of the localized charge depend on the two materials. The drawing assumes the net localized charge to be negative, indicated by a blue line. This localized net charge is shielded by mobile ions in the ionic conductors. Because the concentration of the mobile ions in the ionic conductor is typically much lower than the concentration of free electrons in the metallic electrode, the shielding charge in the ionic conductor is diffused, decaying over the distance of the Debye length. Similarly, a layer of net charge may also localize with a molecular distance from the interface between a dielectric and an ionic conductor. The localized charge is shielded by diffused charge in the ionic conductor. The drawing assumes that the dielectric is perfect and has no mobile charges. The thicknesses are not drawn to scale. The charge density and electric potential near the interfaces vary within the Debye length (some nanometers), but the thicknesses of the dielectric and ionic conductor are of hundreds of microns. (b) In the voltage-on state, the two electrodes are subject to a voltage V. The drawing only shows the excess electric charges and electric potential caused by the applied voltage. The distributions are anti-symmetric with respect to the centerline of the dielectric. The two interfaces between the electrodes and the ionic conductors behave as capacitors, in series with the capacitor made of the dielectric. The charges on the three capacitors are equal.

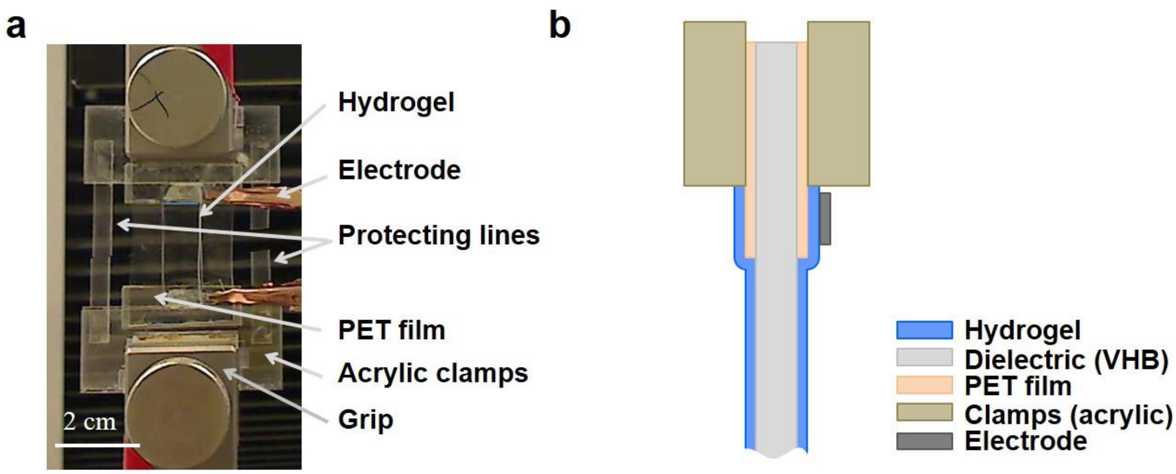

Figure S2 | Design of a strain sensor for uniaxial tensile tests. A strain sensor was fabricated with a special design for a uniaxial tensile test. (a) The sensor was soft, and was fixed to stiff acrylic clamps using a glue (Instant Krazy Glue, Krazy Glue). Furthermore, two stiff protecting lines were glued at the edge of acrylic clamps to prevent a deformation before loading. The protecting lines were cut after placing the sample between the grips. (b) The cross section of the grip. To avoid sliding between the hydrogel, we used the glue to bond a 100 μm thick PET film to the acrylic and the hydrogel.

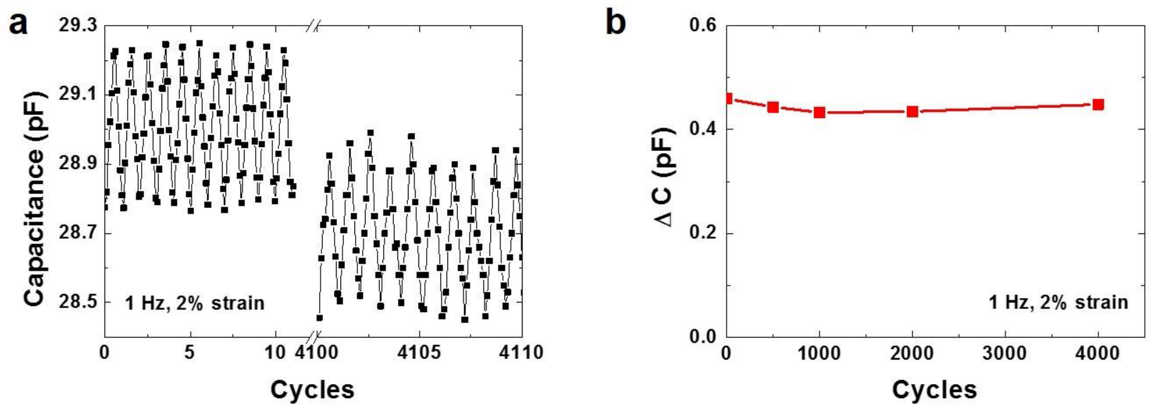

Figure S3 | Characteristics of strain sensors under uniaxial cyclic loading. A strain sensor was subject to uniaxial cyclic loading at a frequency of 1 Hz and a maximum strain of 2%. (a) The capacitance C of the sensor was recorded using a capacitance meter. The capacitance drifted slightly over cycles. For example, the minimum value of the capacitance of each cycle, C_{min}, was 28.77 pF in the initial undeformed state, and was 28.46 pF at cycle number 4110. (b) The change in capacitance in each cycle, $\Delta C = C_{\mathrm{max}} - C_{\mathrm{min}}$, varied less than 5% over 4000 cycles.

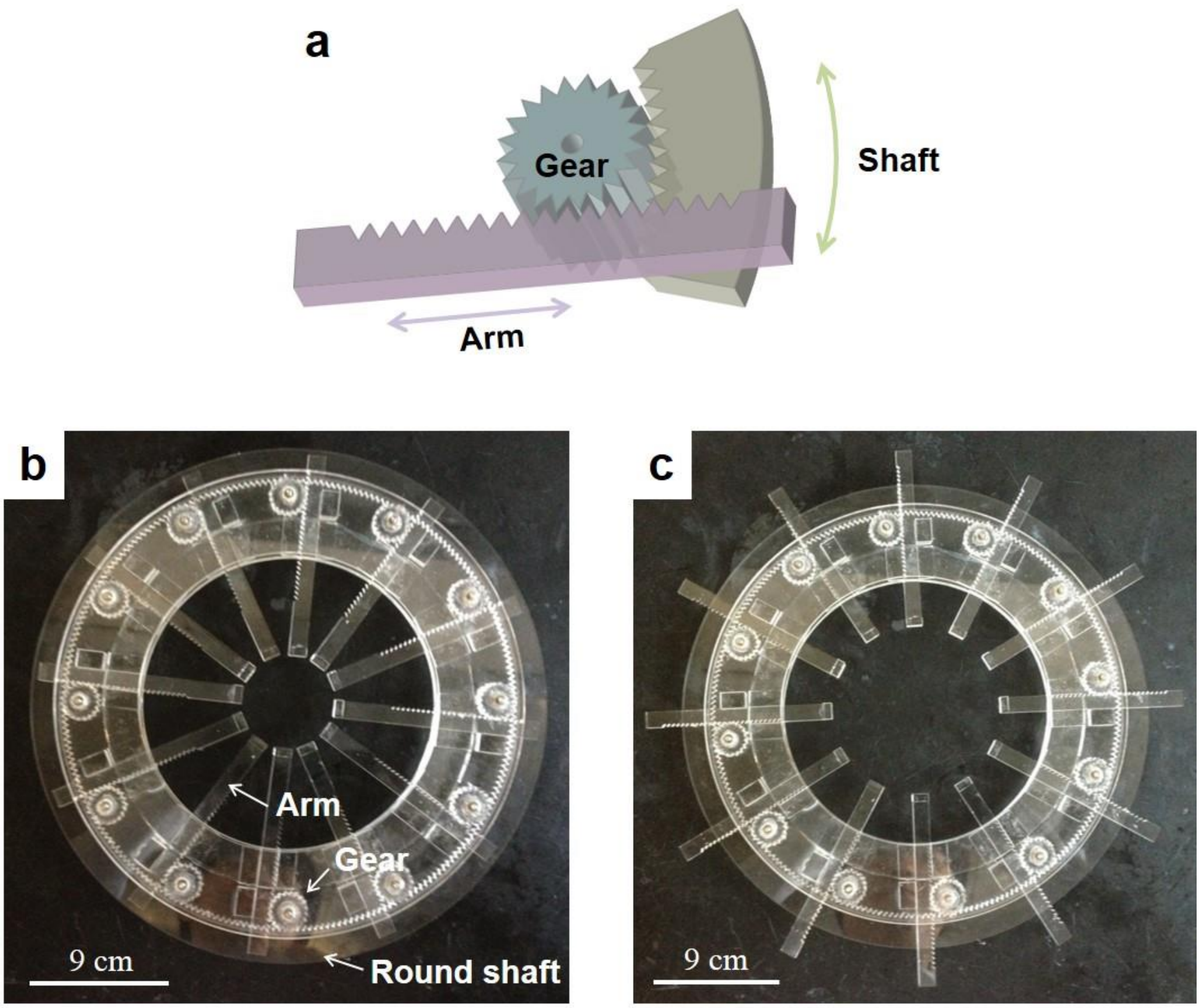

Figure S4 | Equibiaxial stretcher. An equibiaxial stretcher was made of a 3 mm thick acrylic plate (McMaster-Carr, 8560k239). The acrylic plate was cut into the designed shape by using a laser cutting system (VersaLaser VLS3.50, Universal Laser Systems) with 50 W power and 0.84 cm/sec beam speed. When the round shaft is rotated, the rotation is transferred to an arm through a gear. Since the rotation of the shaft is transferring the same amount of movement to 12 arms, the rotation will cause equibiaxial stretching. The stretch can be readily controlled up to 3.

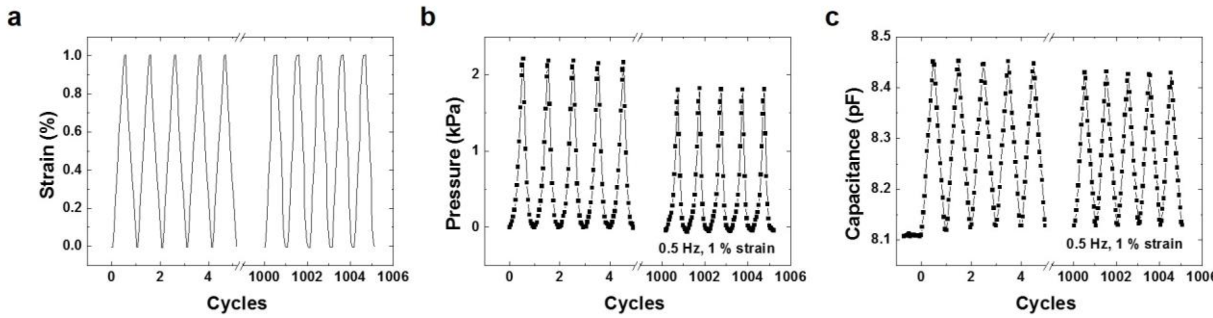

Figure S5 | Characteristics of a pressure sensor under cyclic loading. (a) A pressure sensor was cyclically compressed with a prescribed strain of 1% and a frequency of 0.5 Hz over 1000 cycles. (b) The pressure was measured by a load cell. The pressure decreased somewhat over the cycles, possibly due the viscoelasticity of the materials. (c) The capacitance C of the sensor was monitored by a capacitance meter. In each cycle, let ΔC be the difference in capacitance before and after loading. The difference in capacitance ΔC drifted from 0.34 pF to 0.3 pF over 1000 cycles.