ADVANCED MATERIALS

Supporting Information

for *Adv. Mater.,* DOI: 10.1002/adma.201403093

An Imperceptible Plastic Electronic Wrap

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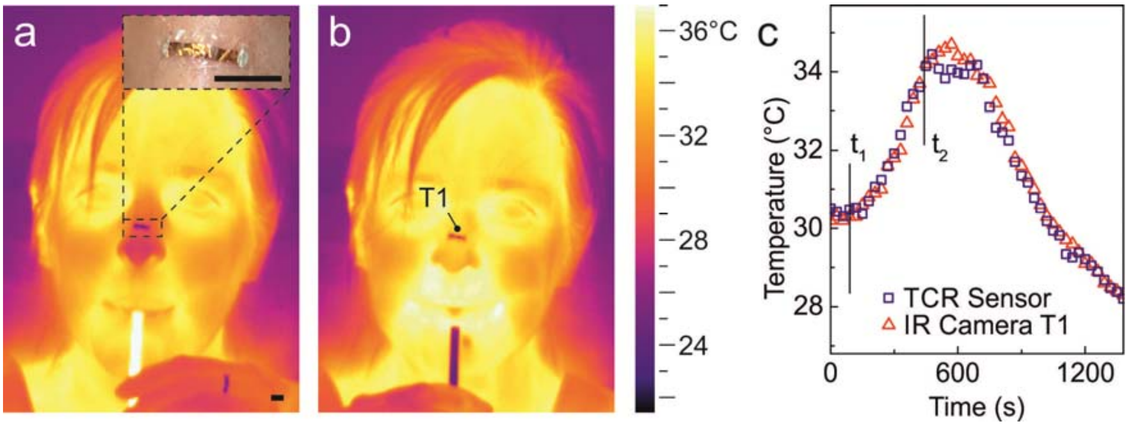

Figure S1: Imperceptible electronic foil as TCR sensor on human skin. The Cu-based resistive temperature sensor adheres to the skin (nose) by means of a band-aid spray (Hansaplast). The skin temperature is monitored both by an IR camera and the imperceptible TCR element in a 4-wire configuration as the volunteer drinks a cup of hot tea and subsequently a glass of cold water. A snapshot of the recorded IR video before drinking tea (at second 90 of the experiment) and before consuming the cold liquid (at second 480) are depicted in Figure S1a and b, together with a photograph of the sensor mounted on the volunteers nose. Scale bar 1 cm. The skin temperature increases by 5 °C within 9 minutes after drinking tea, and falls by 7 °C within X min after drinking cold water (Figure S1c). There is remarkable agreement between the temperature recordings of the IR camera and the TCR sensor.

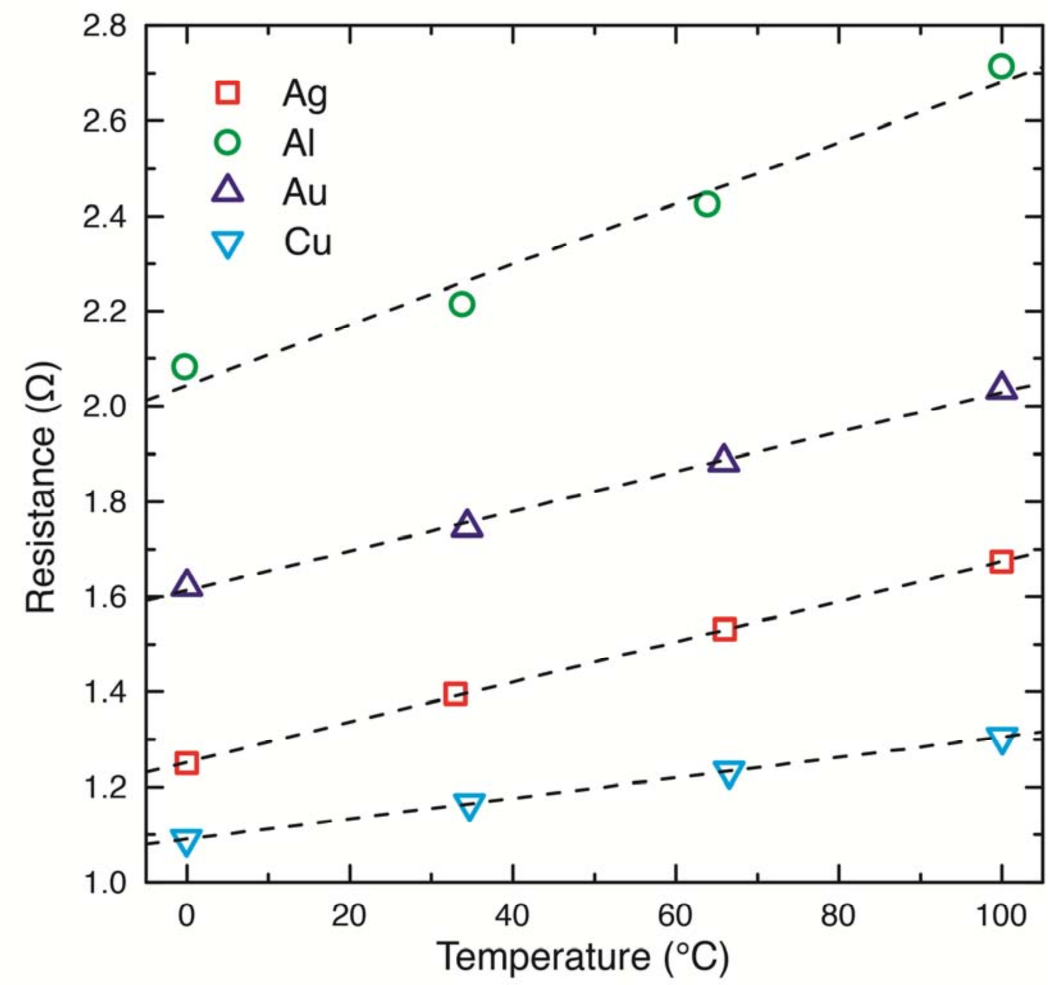

Figure S2: Temperature coefficient of resistance for Al, Ag, Au and Cu-based imperceptible temperature sensors. The 1.4 µm PET stripes with Al, Ag, Au and Cu electrodes where placed on a copper block, good thermal contact was established with heat transfer paste between the copper heat sink and the PET foil. The resistance of the metal electrodes was measured in a 4-wire configuration with a multimeter (Keithley 2000), the temperature of the sample was recorded using a FLIR A325sc infrared camera. The copper block with the specimen was first cooled below 0 °C and then continuously ramped to over 100 °C with a hotplate. The measured temperature dependent resistance of all four metals (Figure S2) was used to calibrate the temperature sensors, with temperature coefficients of 0.00214 K^{-1} (Cu), 0.00417 K^{-1} (Au), 0.00423 K^{-1} (Ag) and 0.00637 K^{-1} (Al).

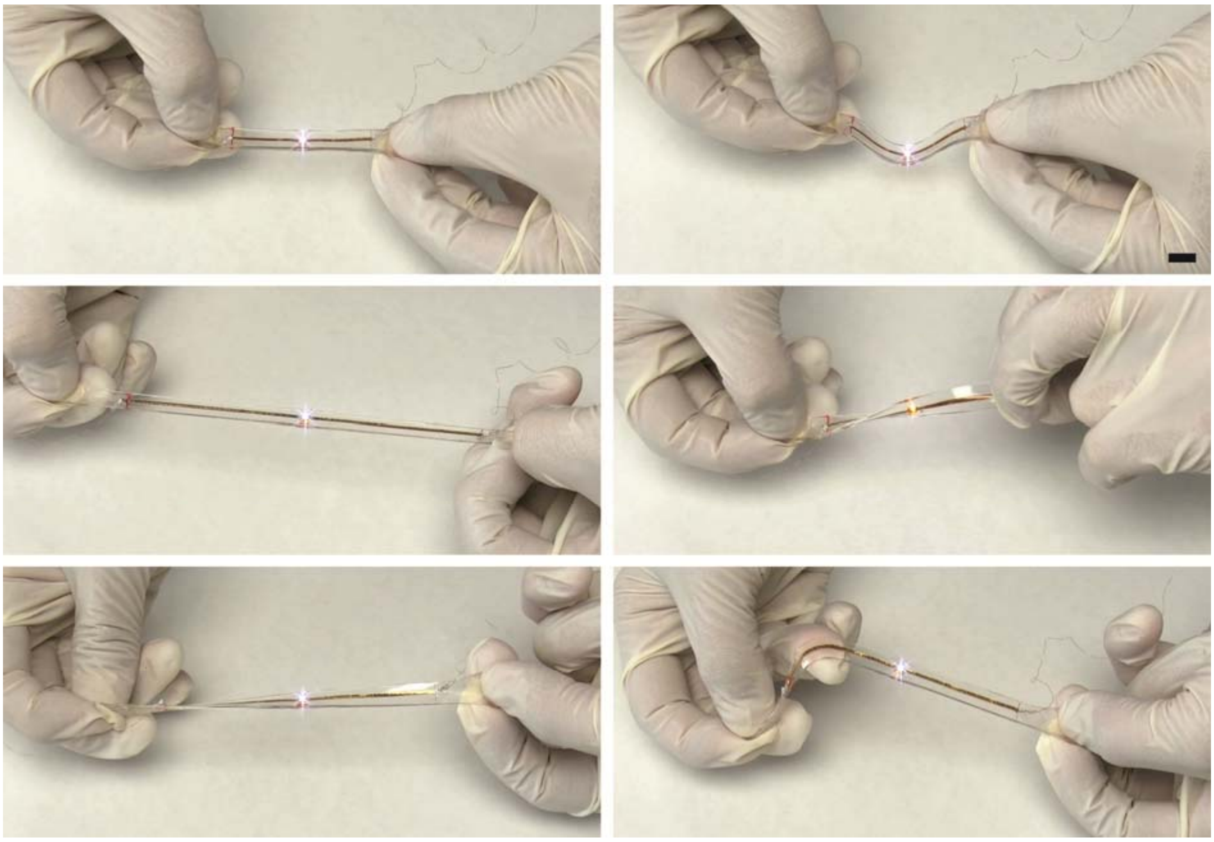

Figure S3: Highly stretchable and twistable white SMD LED light stripe. Stretchable Au interconnects power a white SMD LED placed on a strain-isolated island. The strain-independent conductivity allows unaltered operation of the light stripe during stretching, twisting and deformation, as depicted in the still images taken of SI Video 2. Scale bar 1 cm.

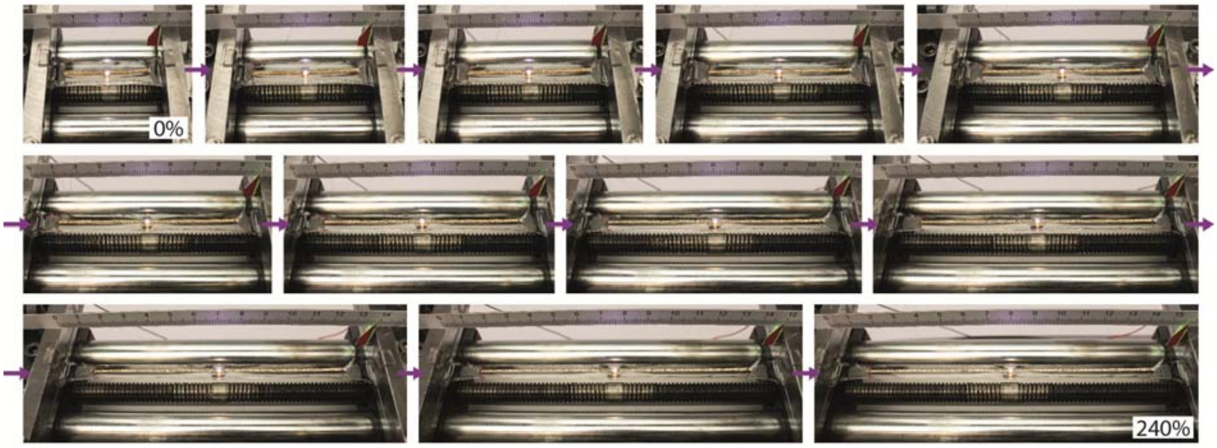

Figure S4: White SMD LED light stripe stretched to 240%. Image sequence of a light stripe with a white SMD LED centered between Au stretchable interconnects. A constant current of 5 mA powers the LED. No change in light emission was observed when continuously stretching the stripe up to 240% tensile in a custom-made computer-controlled uniaxial stretcher.

Figure S5: Biaxially stretchable 2D-LED circuit: Image of the circuit mounted in a radial stretching device, the LEDs are driven with a constant current of 10mA. The patterned ultrathin Au electrode circuit is transferred to a double layer of VHB elastomer tape. The elastomeric matrix contains Polyimide rigid islands of 3 mm diameter at the positions of the SMD LEDs that effectively reduce strain at the non-stretchable nodes. Repeated biaxial stretching of the 2D-circuit with an aerial expansion factor of 2.5 does not impair its functionality. Scale bar 20 mm.

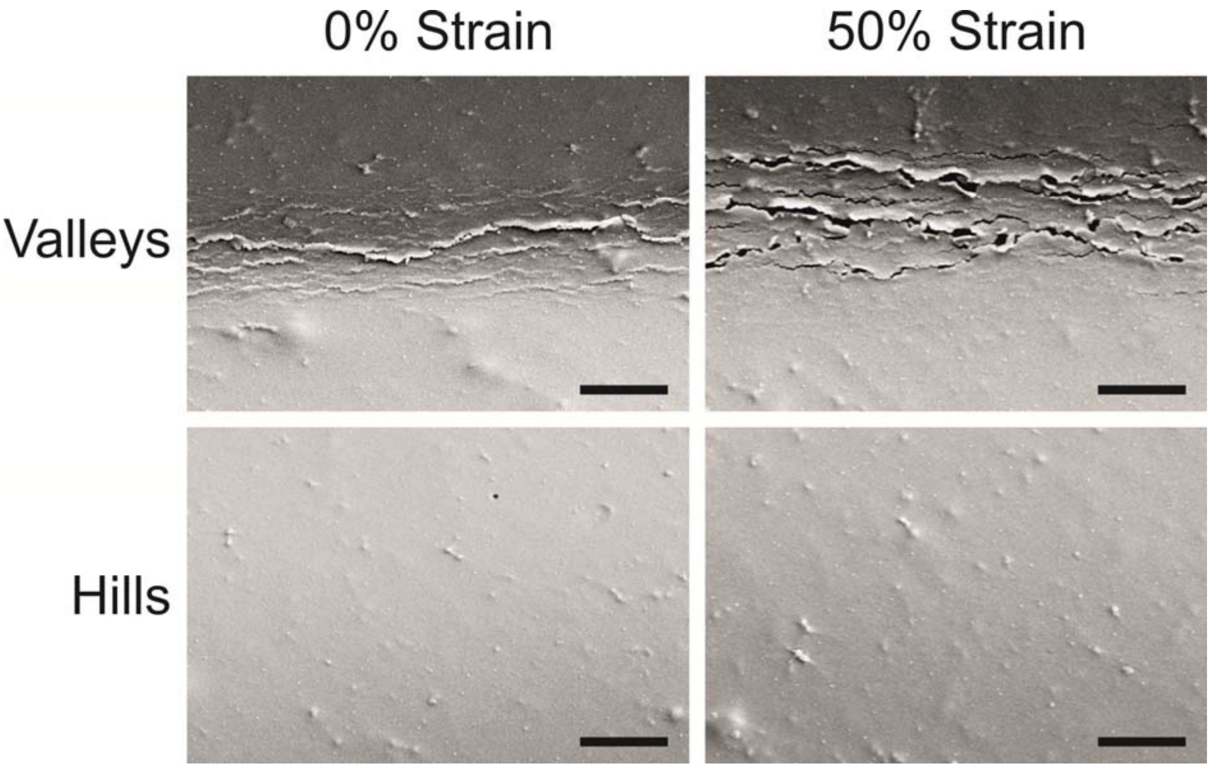

Figure S6: SEM images of a fatigued Al stretchable conductor. Al samples typically fail after 400 stretch cycles to 50% strain. Figure S5 shows high magnification SEM images of the fatigued sample taken in the fully compressed state (0% strain) and when stretched to 50%. Over time, cracks that open and close during a strain cycle form at the valleys of the folds. Once opened cracks immediately form a natural oxide layer, which results in a strain-independent increase of resistance. No cracking was observed at the hills of the folds, suggesting that compressive strains in the aluminum film are the dominant cause of film fracture and ultimately device failure. Scale bars 5 μm.

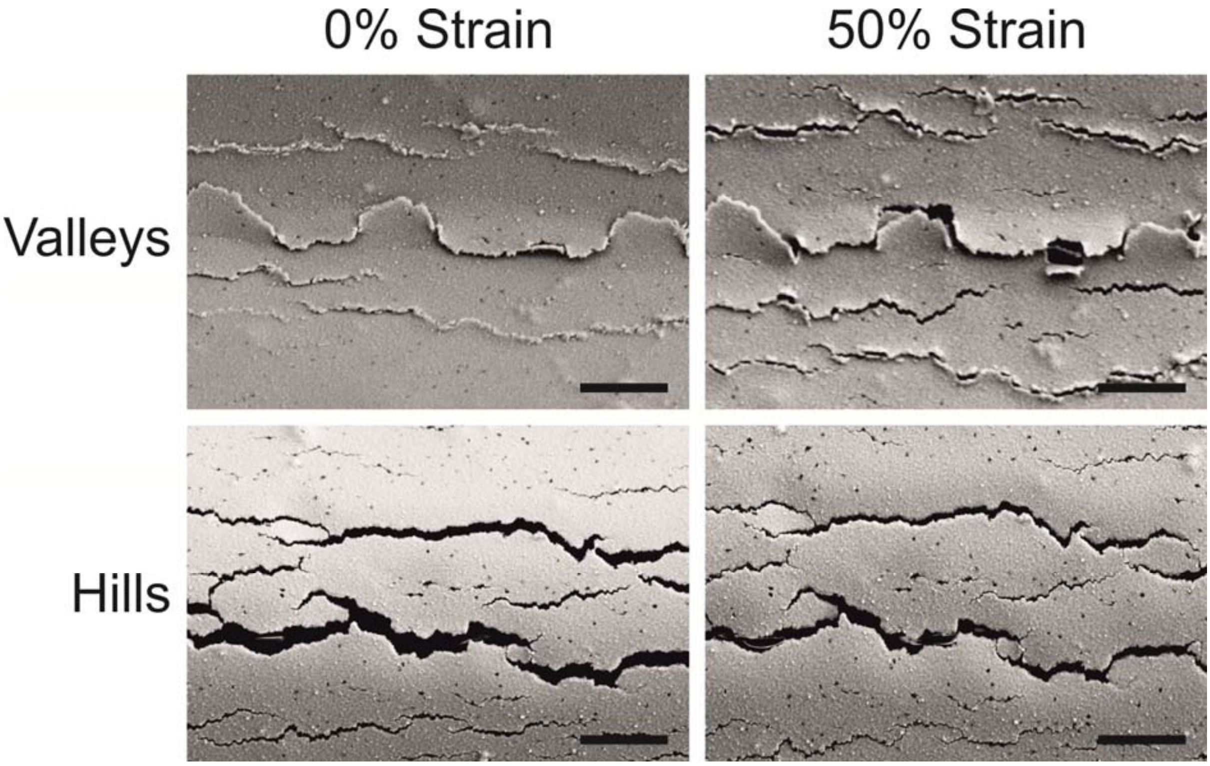

Figure S7: SEM images of a fatigued Ag stretchable conductor. Ag samples endure over 1,000 stretch cycles to 50% strain, but develop cracks that cause a 2-fold increase of resistance. Figure S5 shows high magnification SEM images of the fatigued sample taken in the fully compressed state (0% strain) and when stretched to 50%. Here, cracks that open and close during a strain cycle form at both the valleys and hills of the folds. Ag does not form a passivation oxide layer, thus the opening and closing of the cracks results in a strain-dependent resistance. Scale bars 2 μm.

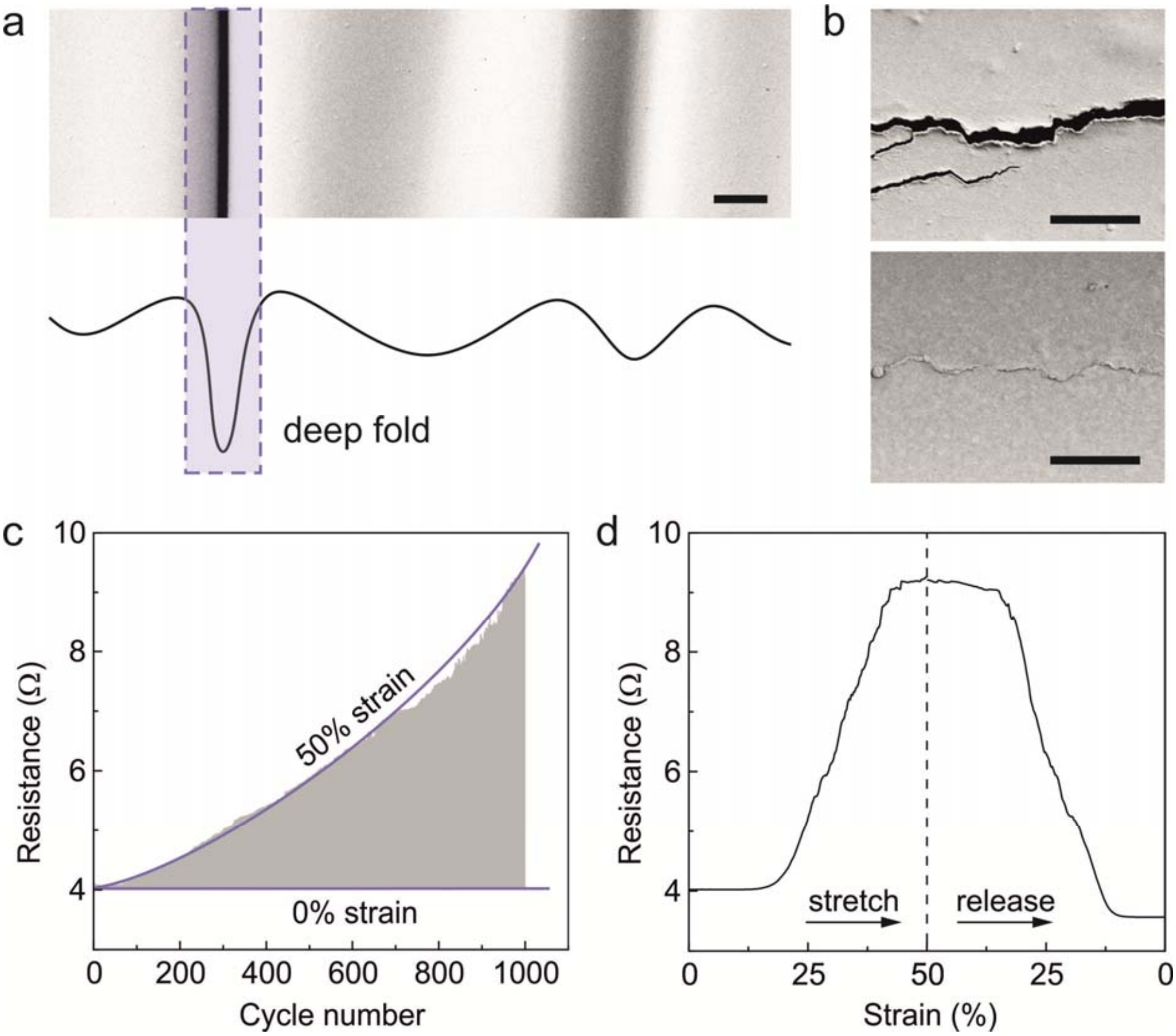

Figure S8: Impact of deep folds on reliability. During the course of fatigue experiments 8 gold conductors were tested. Consecutive scanning electron microscope images showed that samples were prone to an increase in resistance as function of strain when deep folds were present. Deep folds have very sharp edges with bending radii smaller than 2 µm. Typically samples exhibiting deep folds show overall irregular wrinkling with alternating deep and shallow creases. Figure S7 a shows a SEM image of such a gold electrode with deep and shallow wrinkles and a cross sectional height profile estimation. (Scale bar 40 µm) The electric resistance of this gold electrode as a function of cycle number is shown in Figure S7 c. While the samples resistance minimum strain remains constant when no strain is applied over 1,000 cycles, its resistance at maximum strain increases consecutively with cycle number. The resistance during a single stretching cycle increases with increasing strain (d) as the cracks in the electrode are opening up (b). Upon strain release the resistance decreases to its initial value and the cracks remain fully closed. Scale bar 5 µm.

Supplementary Video 1: **Imperceptible electronics on soap film**: 3 imperceptible gold electrodes on 1.4 µm thick PET foil float freely on a soap film.

Supplementary Video 2: **Hybrid rigid island LED stripe**: A stretchable hybrid LED strip is stretched and twisted remaining functional.

Supplementary Video 3: **Stretchable 2D-LED array**: A hybrid rigid island array of red and green LEDs is biaxially stretched and released without effect on functionality.

Supplementary Video 4: **Cyclic fatigue of stretchable electrode**: A stretchable silver conductor is fatigued by cycling stretching to 50%.