Supporting Information

A Highly Sensitive and Very Stretchable Strain Sensor Based on A Rubbery Semiconductor

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1) Feasibility of AgNW conductor composite for the strain sensor

To examine the feasibility of using the AgNW/PDMS conductors for the rubbery strain sensor, we prepare gold nanoparticles (AuNPs) conformally coated on the AgNW (AuNP-AgNW) electrodes through a galvanic replacement process[1]. Though it is expected that AuNP coated AgNW would lower the energy barrier between the electrode and the P3HT semiconductor[2], similar electrical current from the sensor with the AgNW/PDMS and AuNP-AgNW/PDMS electrodes are obtained. The results suggest that the AgNW/PDMS conductor is also suitable for constructing the rubbery strain sensors. (Figure S3).

2) Calculation of resistance of P3HT-NF/PDMS based on 3D percolation theory

Based on the 3D percolation theory, the electrical conductivity of the percolated composite materials uses the following formula[3-5]:

$$\sigma \propto (V_f - V_c)^S \tag{1}$$

where σ is the electrical conductivity of the composite, V_f and V_c are the volumetric fraction of the filler and the filler at percolation threshold, respectively. S is the fitting parameter, which is used to best fit the experimental results. Assuming that the P3HT-NF are evenly distributed within the PDMS matrix, thus the areal fraction of the P3HT-NF equals to the volumetric ratio of the composite, i.e. $V_f = D_f$, and $V_c = D_c$. The electrical conductivity can be expressed as the following:

$$\sigma \propto (D_f - D_c)^S \tag{2}$$

Since the electrical resistance $R = \frac{1}{\sigma} \cdot \frac{l}{wt}$, where t, w and l are thickness, width and length of the elastomeric semiconductor nanocomposite, respectively, equation (2) can be rewritten as:

$$R \propto (D_f - D_c)^{-S} \tag{3}$$

In the experiment, the length (l) and width (w) of the elastomeric semiconductor nanocomposite are 50 μm and 1 mm, respectively. D_f is determined by the areal fraction of

P3HT-NF to PDMS matrix from the AFM phase images at different levels of mechanical stretching as shown in Figure S7. The D_f values at 0%, 20% 60% and 100% strain are 0.30, 0.22, 0.19 and 0.18, respectively. Note that D_f values are obtained from the phase angle distribution curve (SPIP™, Image Metrology). D_c is calculated with an assumption for isotropic, soft-core cylinders by using the following formula[6]:

$$D_c = V_c = \frac{N_c \cdot (\pi R^2 L)}{V} = \frac{\pi R^2 L}{8\pi R^2 L + \pi L^2 R} \tag{4}$$

where N_c and V are the number of fillers required for the percolation and the total sample volume, respectively. Based on the TEM (Figure S4) and AFM (Figure S5) images, the radius of P3HT-NF, R, is 40 nm and the length, L, ranges from 700 nm to 1.3 µm. D_c values for 700 nm and 1.3 µm are 0.030 and 0.025, respectively. Figure S7 shows the comparison of the electrical resistance and GF of the P3HT-NF/PDMS semiconductor nanocomposite (S10) obtained from the experiment and calculation based on the percolation theory. Note that the electrical resistance and GF obtained from the percolation theory are in good agreement with the experimental results.

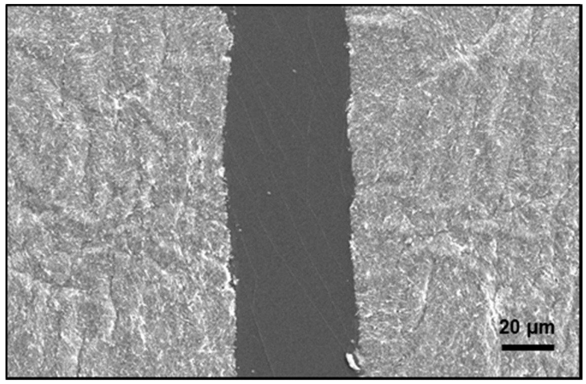

Figure. S1. SEM image of patterned AgNW/PDMS conductors of a strain sensor.

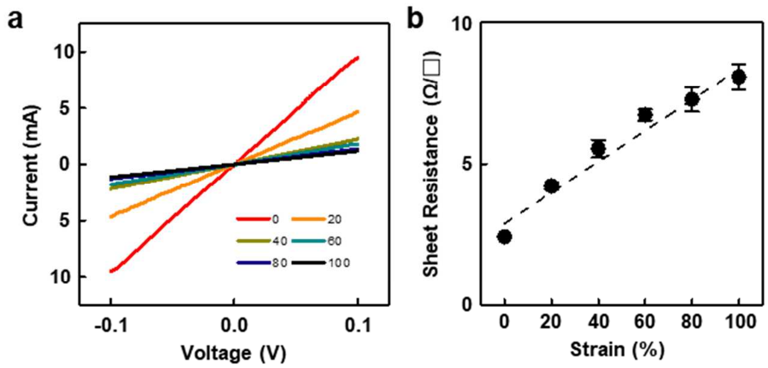

Figure. S2. (a) The measured I-V curves and (b) the measured electrical resistance of AgNW/PDMS conductors under different levels of mechanical strain along the length direction.

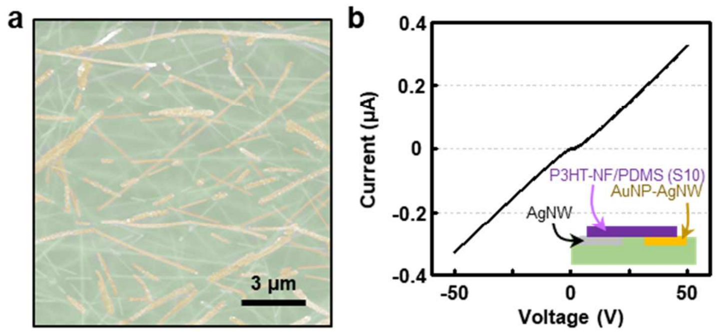

Figure. S3. (a) SEM image of AuNP-AgNW/PDMS after Galvanic replacement process. Green and yellow colors indicate the PDMS and AuNP-AgNW, respectively. (b) I-V curve of the strain sensor with AgNW/PDMS and AuNP-AgNW/PDMS electrodes.

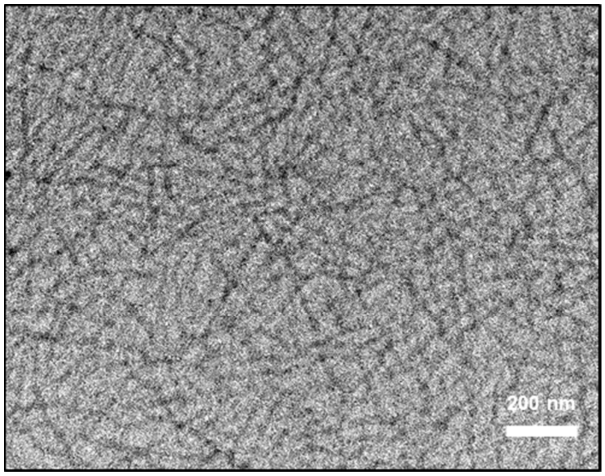

Figure. S4. TEM image of the P3HT-NFs fabricated by using the cooling process.

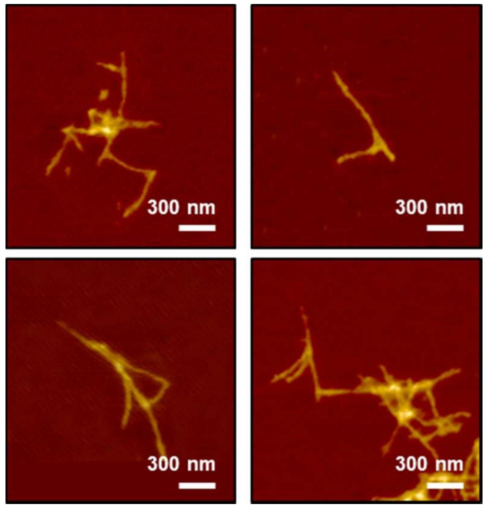

Figure. S5. AFM images of P3HT-NFs fabricated by using the cooling process.

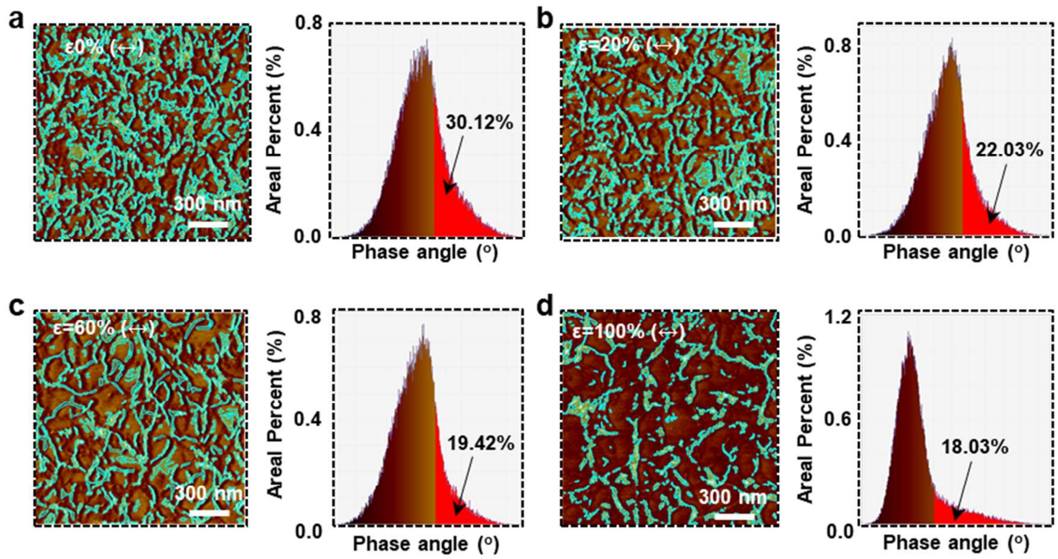

Figure. S6. Areal ratio of P3HT-NFs to PDMS from the AFM phase mode images with different levels of uniaxial mechanical stretching at (a) 0% (b) 20% (c) 60% and (d) 100%.

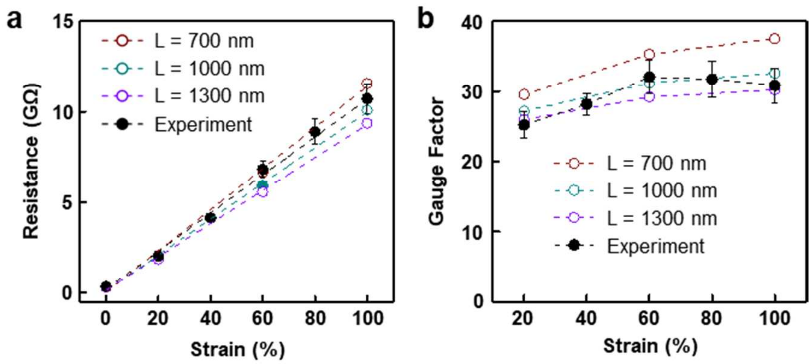

Figure. S7. Comparison of (a) the electrical resistance and (b) the gauge factor of the P3HT-NF/PDMS semiconductor nanocomposite (S10) obtained from the experiment and calculation based on the percolation theory.

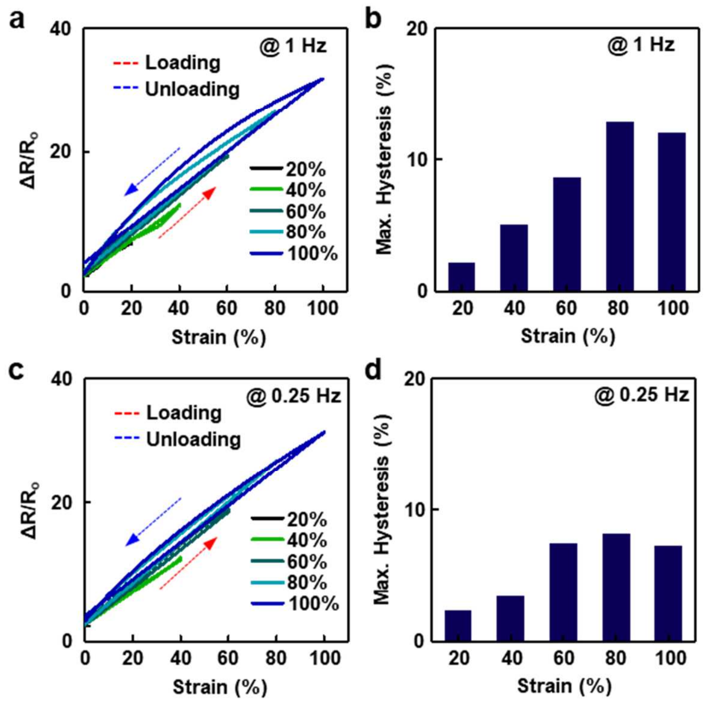

Figure. S8. (a) The loading/unloading curves and (b) the corresponding maximum hysteresis of the strain sensor (S10) with different levels of mechanical strain at 1 Hz. (c) The loading/unloading curves and (d) the corresponding maximum hysteresis of the strain sensor (S10) with different levels of mechanical strain at 0.25 Hz.

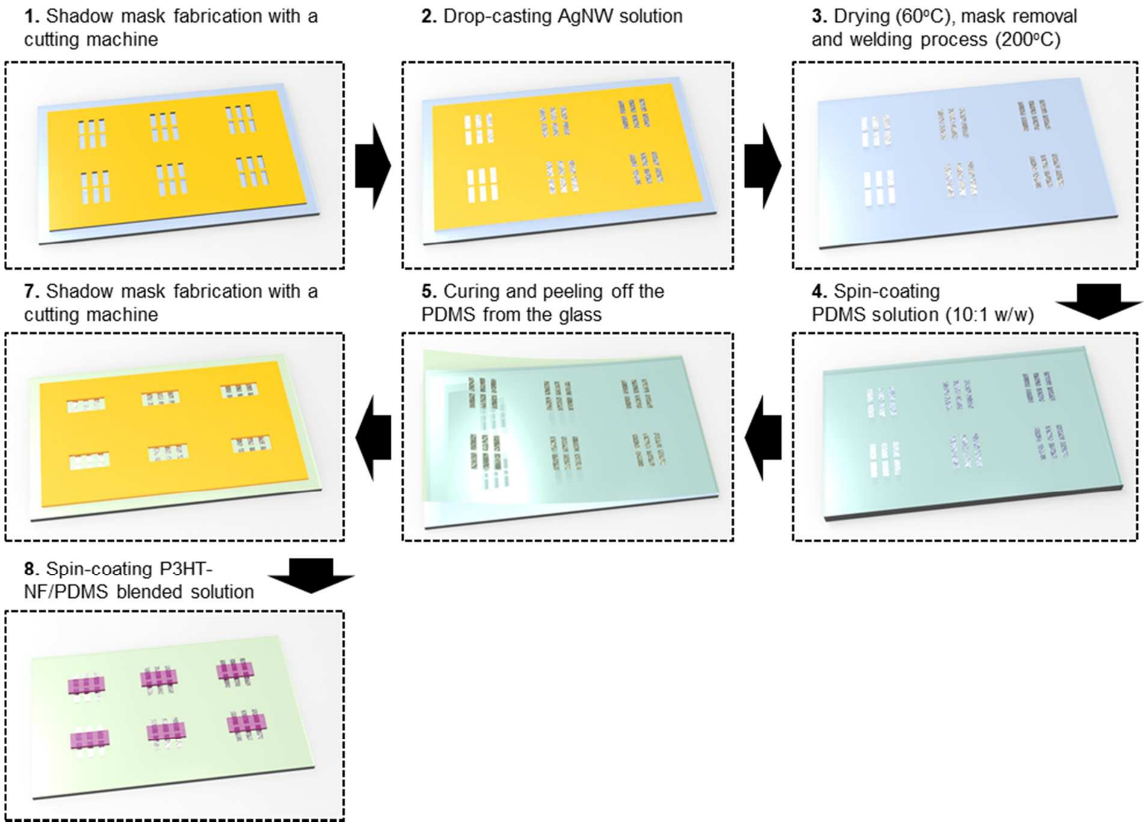

Figure. S9. The fabrication steps of the rubbery strain sensors.

References

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