
Elastic electronics based on micromesh-structured rubbery semiconductor films

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Supplementary Information

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Supplementary Notes

Supplementary Note 1. Characteristics of the FETs.

The field-effect mobility (μ_{FE}) was calculated by fitting the plot of the linear regime of the square root of the drain current ($\sqrt{I_{DS}}$) versus gate voltage (V_{GS}) curve based on the following equations:

$$I_{DS} = \frac{WC_i\mu_{FE}}{2L} (V_{GS} - V_{TH})^2 \quad (S1)$$

$$\sqrt{I_{DS}} = \sqrt{\frac{WC_i\mu_{FE}}{2L}} (V_{GS} - V_{TH}) = \sqrt{\frac{WC_i\mu_{FE}}{2L}} V_{GS} - \sqrt{\frac{WC_i\mu_{FE}}{2L}} V_{TH} \quad (S2)$$

$$Slope = \sqrt{\frac{WC_i\mu_{FE}}{2L}} \quad (S3)$$

$$\mu_{FE} = \frac{2L}{WC_i} (Slope)^2 \quad (S4)$$

where L and W are the length and width of the channel. The C_i is the gate insulator capacitance per unit area. I_{DS} is the drain current, and μ is the field-effect mobility, respectively. V_{GS} is the gate voltage, V_{TH} is the threshold voltage. Note that mobility value of ion gel-based transistors were calculated based on the basis of the specific capacitance of the ion gel of $9.8 \mu F/cm^2$ at 1 Hz.

Supplementary Note 2. ECG data processing

To process the electrocardiograms from each sensing node of the rubbery transistor array, the raw data was first imported into MATLAB. Custom IIR filters were designed, and their frequency response was observed. A 60 Hz comb filter (third-order) was applied to remove power line noise and its harmonics from the raw data. A third-order bandpass filter with cutoff frequencies of 1 and 40 Hz was then applied to recover the physiologically relevant cardiac potentials.

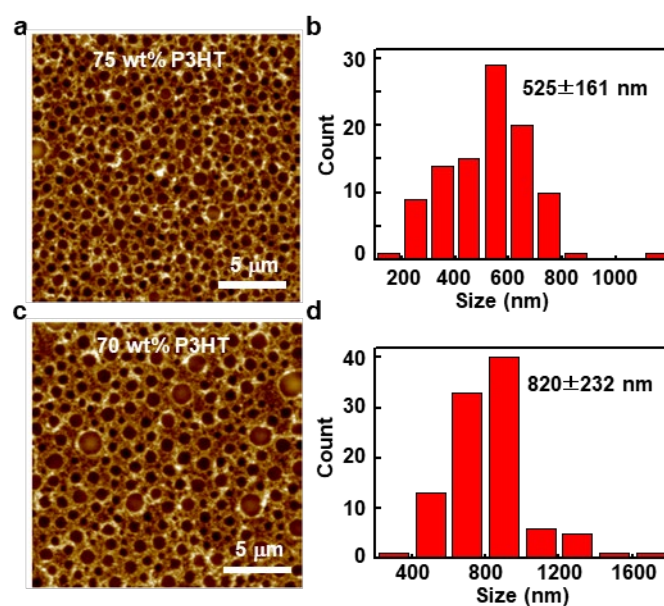
Supplementary Note 3. SNR calculation for ECG signals

To calculate the SNR for each rubbery transistor-based sensing node, the power spectral density estimate was first obtained using Welch's method in MATLAB. The parameters for the pwelch function were chosen to be a 2000-point Hanning window (i.e., our sampling frequency) and a 50% overlap. The frequency range of interest for ECG signals is typically below 100-120 Hz. As shown in Supplementary Fig. 20, the region below 100 Hz (in blue) was chosen to represent our signal in the SNR calculation, and the power was summed over those frequencies and normalized to be in units of dB. The noise was averaged from the region shown in red (800-900 Hz), and this range was chosen because it was obviously in the noise floor. The following formula was used to convert the ratio of the signal and noise to power in dB:

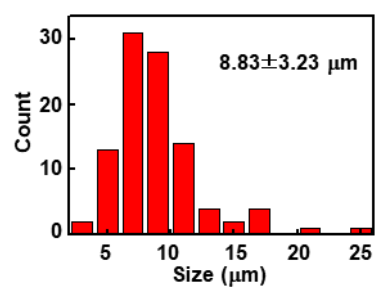
$$SNR = 10 * \log_{10} \frac{P_{(s)}}{P_{(n)}} \quad (S5)$$

where $P_{(s)}$ is the power of the signal and $P_{(n)}$ is the power of the noise. This approach for calculating the SNR was used for the signals shown in Figure S19 and Figure 6c. It should be noted that if the noise was averaged across all frequencies greater than our signal of interest (i.e., >100 Hz) instead of the 800-900 Hz range, the SNR values changed negligibly.

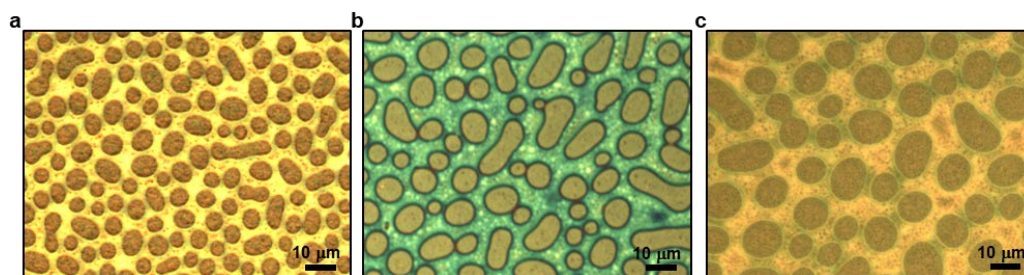
Supplementary Figures



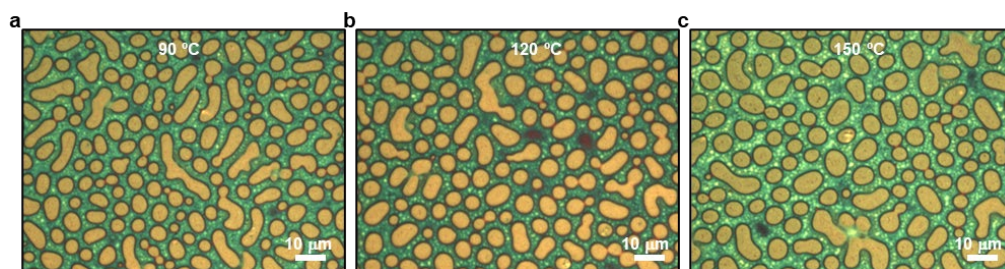
Supplementary Fig. 1. **a**, AFM images of 75 wt% P3HT composite film. **b**, The domain size analysis for 75 wt% P3HT composite film. **c**, The AFM images of 70 wt% P3HT composite film. **d**, The domain size analysis for 70 wt% P3HT composite film.



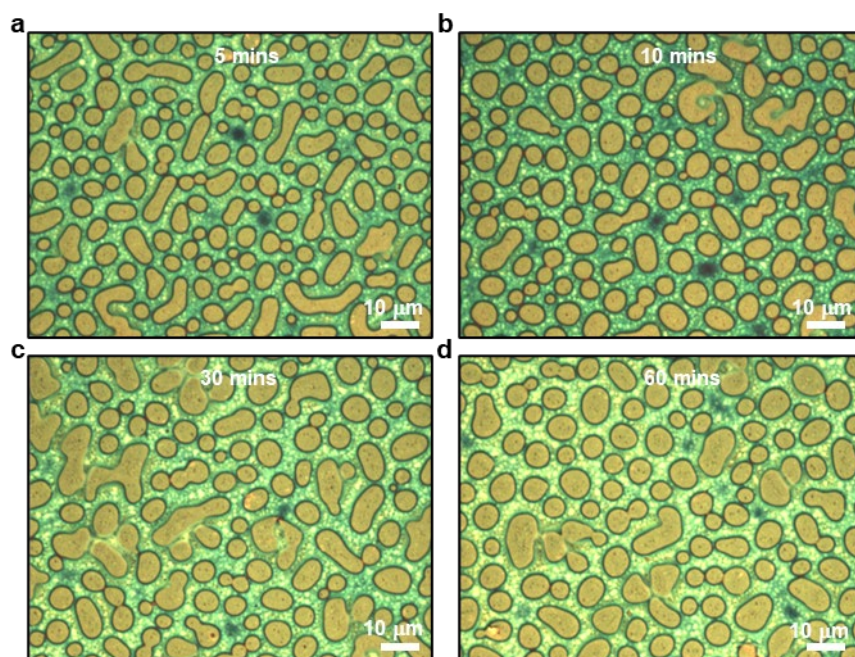
Supplementary Fig. 2. Domain size analysis for 65 wt% P3HT composite film.



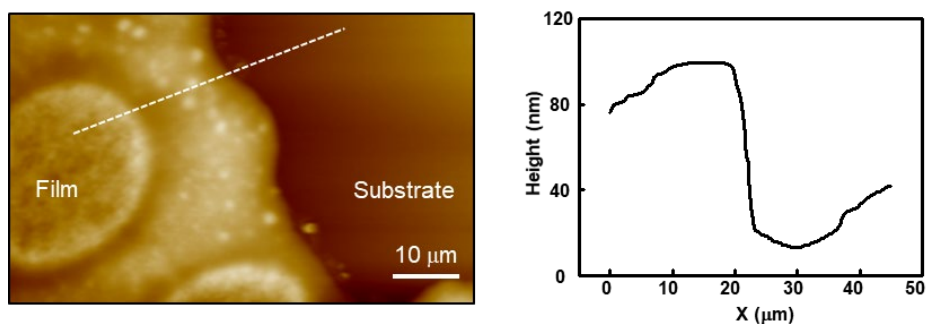
Supplementary Fig. 3. Optical images of 65 wt% P3HT composite film deposited on different substrates **a**, glass **b**, SiO₂/Si **c**, PDMS.



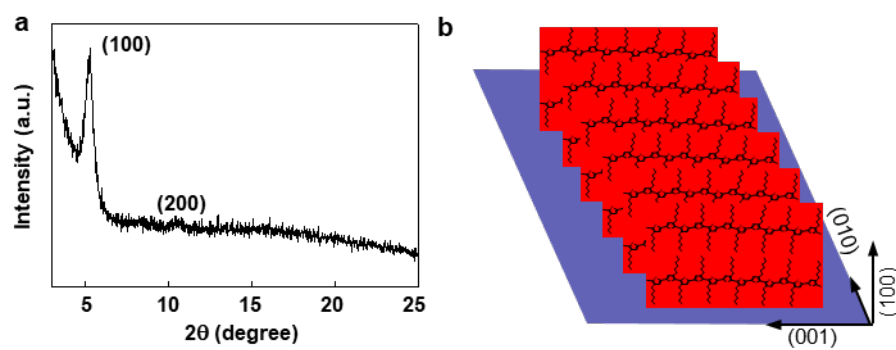
Supplementary Fig. 4. Optical images of 65 wt% P3HT composite film deposited on SiO₂/Si substrate annealed at different temperatures **a**, 90 °C **b**, 120 °C **c**, 150 °C.



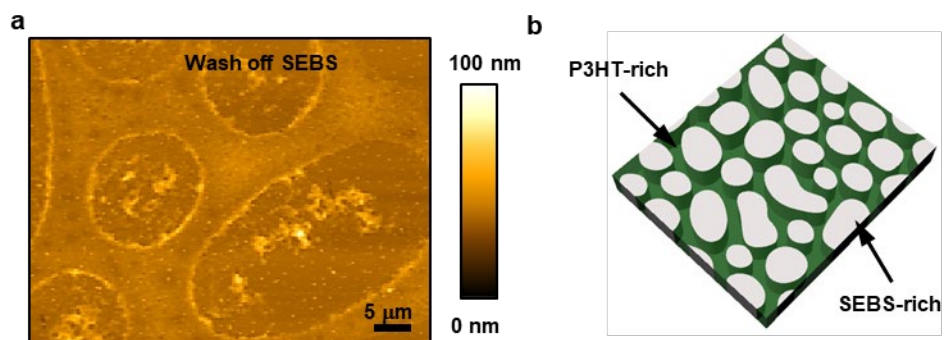
Supplementary Fig. 5. Optical images of 65 wt% P3HT composite film deposited on SiO₂/Si substrate annealed at 150 °C for different times: **a**, 5 mins **b**, 10 mins **c**, 30mins **d**, 60mins.



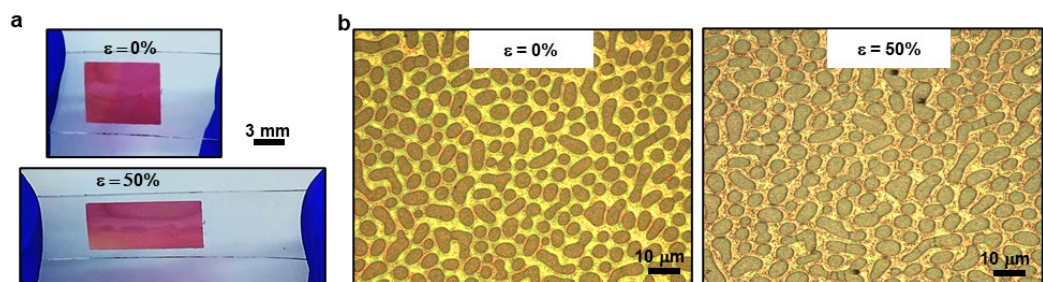
Supplementary Fig. 6. Typical thickness measurement of the LPSM-1 film using AFM.



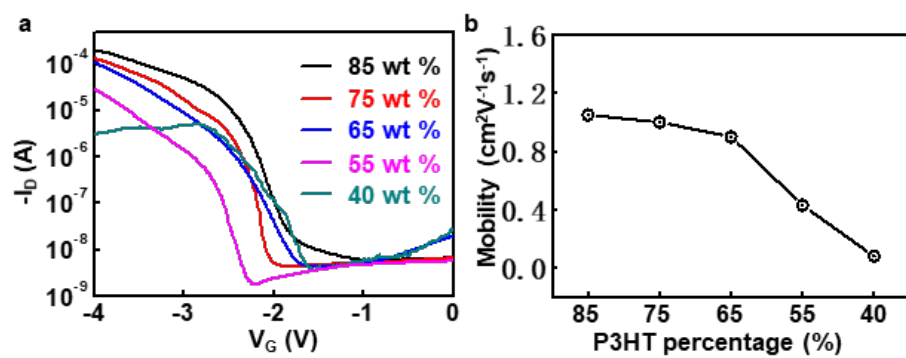
Supplementary Fig. 7. a, XRD pattern of the LPSM-1 film. **b**, Schematic illustration of the P3HT packing structure in the LPSM-1 film.



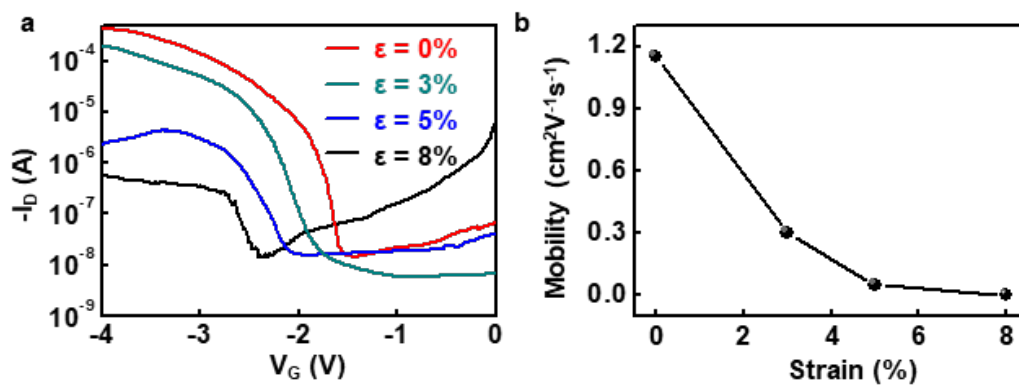
Supplementary Fig. 8. **a**, AFM image of the LPSM-1 film after washing off SEBS. **b**, Schematic diagram of the composition of the LPSM-1 film.



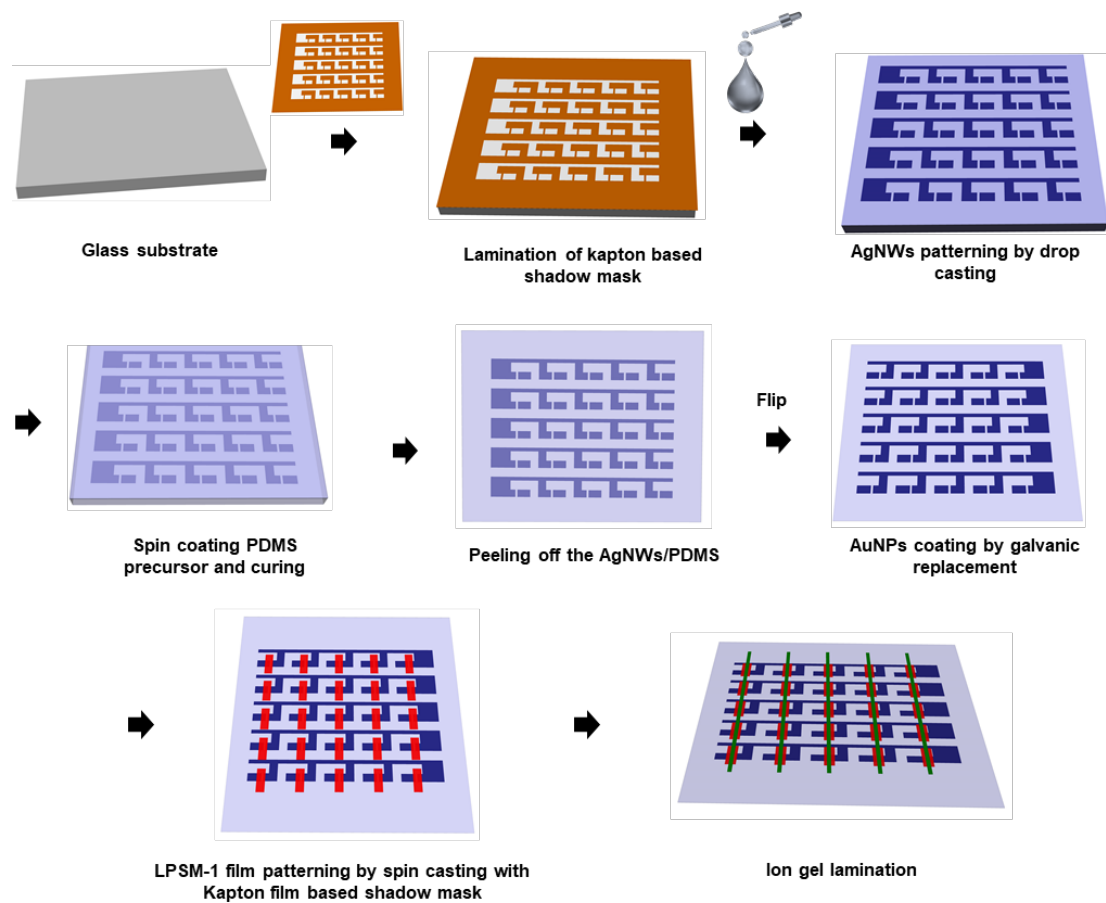
Supplementary Fig. 9. **a**, Photograph of the LPSM-1 film deposited on PDMS substrate without and with 50% strain. **b**, Optical images of the LPSM-1 film deposited on PDMS substrate without strain and with 50% strain.



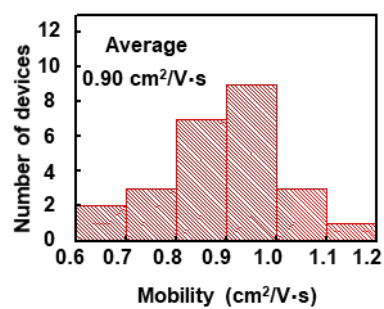
Supplementary Fig. 10. **a**, Representative transfer curves of the composite thin film with different percentages of P3HT. **b**, Mobility values of the composite thin film-based transistor with different percentages of P3HT.



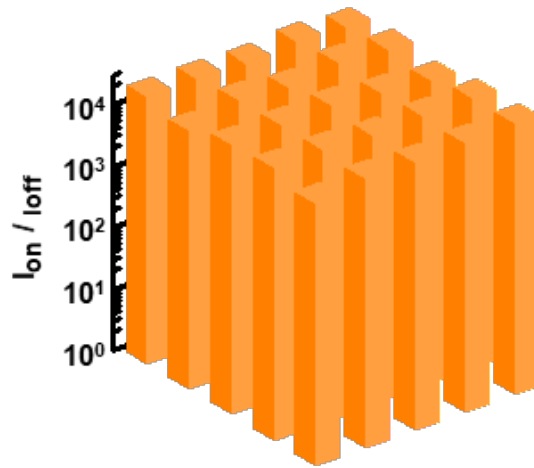
Supplementary Fig. 11. a, The transfer curves of the transistor based on the pure P3HT thin film at different strain. **b**, Mobility values of the pure P3HT thin film-based transistor at different strain.



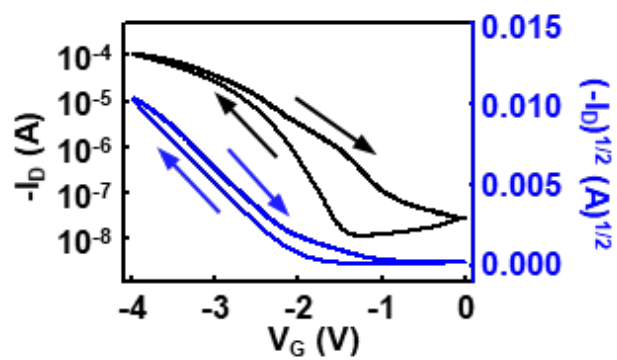
Supplementary Fig. 12. Fabrication process of the transistor array based on the LPSM-1 film.



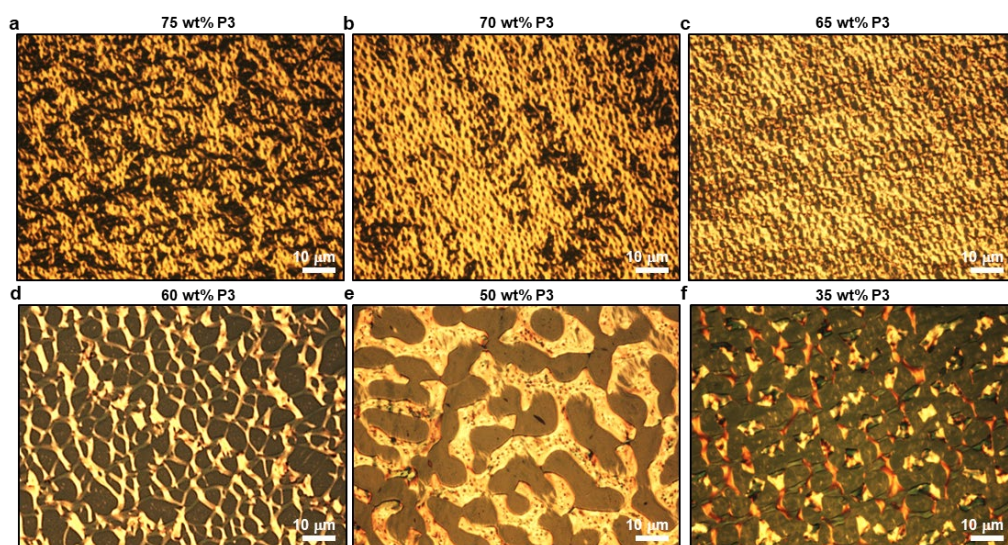
Supplementary Fig. 13. Mobility value distribution of the transistor array based on the LPSM-1 film.



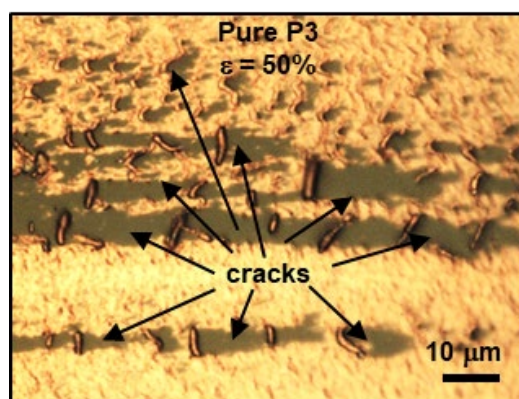
Supplementary Fig. 14. I_{on}/I_{off} map of rubbery transistors array based on the LPSM-1 film.



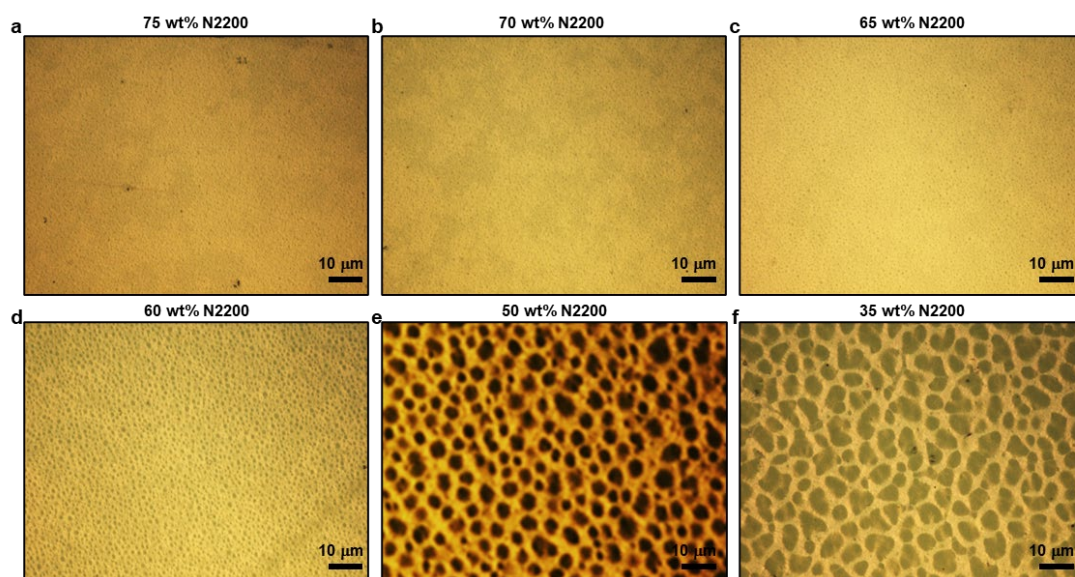
Supplementary fig. 15. The hysteresis loop of the transfer curve for the rubbery transistor at a scan rate of 10 mV/s.



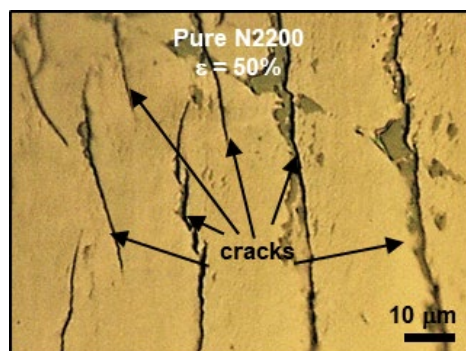
Supplementary Fig. 16. Optical images of P3/PU film with different weight ratios a, 75 wt% P3 b, 70 wt% P3 c, 65 wt% P3 d, 60 wt% P3 e, 50 wt% P3 f, 35 wt% P3.



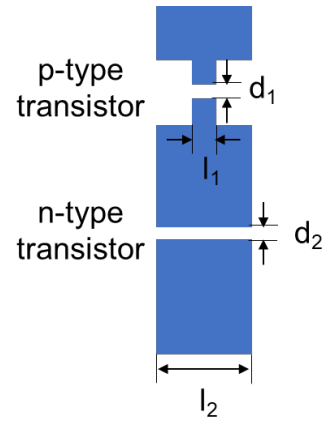
Supplementary Fig. 17. Optical image of pure P3 film at 50% strain.



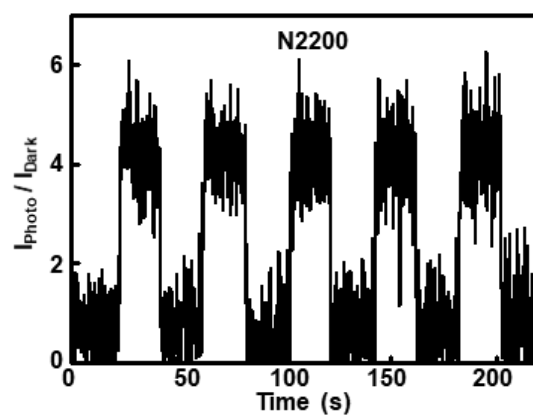
Supplementary Fig. 18. Optical images of N2200/PU film with different weight ratios **a**, 75 wt% N2200 **b**, 70 wt% N2200 **c**, 65 wt% N2200 **d**, 60 wt% N2200 **e**, 50 wt% N2200 **f**, 35 wt% N2200.



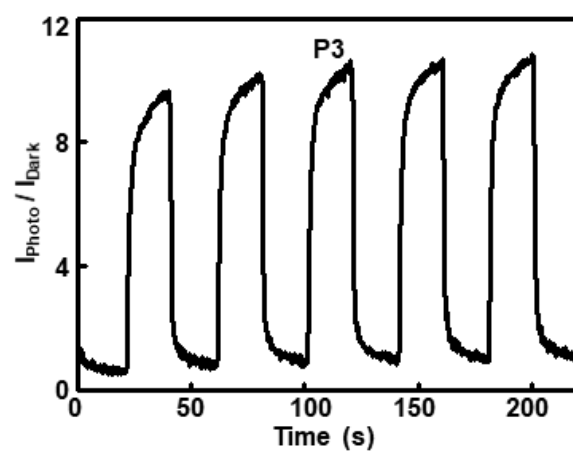
Supplementary Fig. 19. Optical image of pure N2200 film at 50% strain.



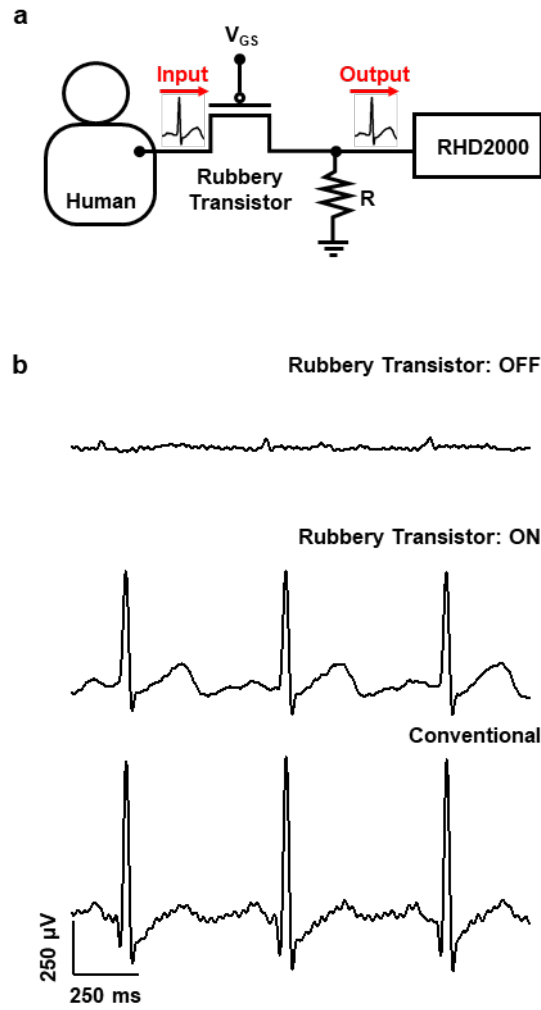
Supplementary Fig. 20. The electrodes layout of the CT inverter (Here, $d_1 = d_2 = 100 \mu\text{m}$, and $4l_1 = l_2 = 4 \text{ mm}$).



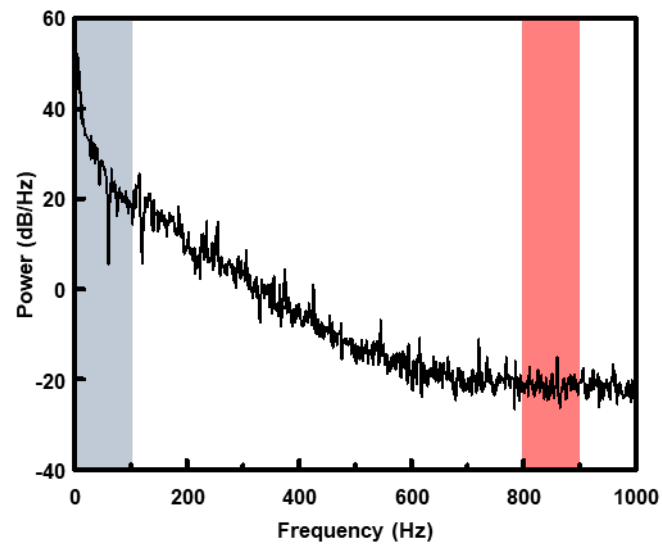
Supplementary Fig. 21. Time-dependent photocurrent response of the pure N2200 based photodetector at 0% strain.



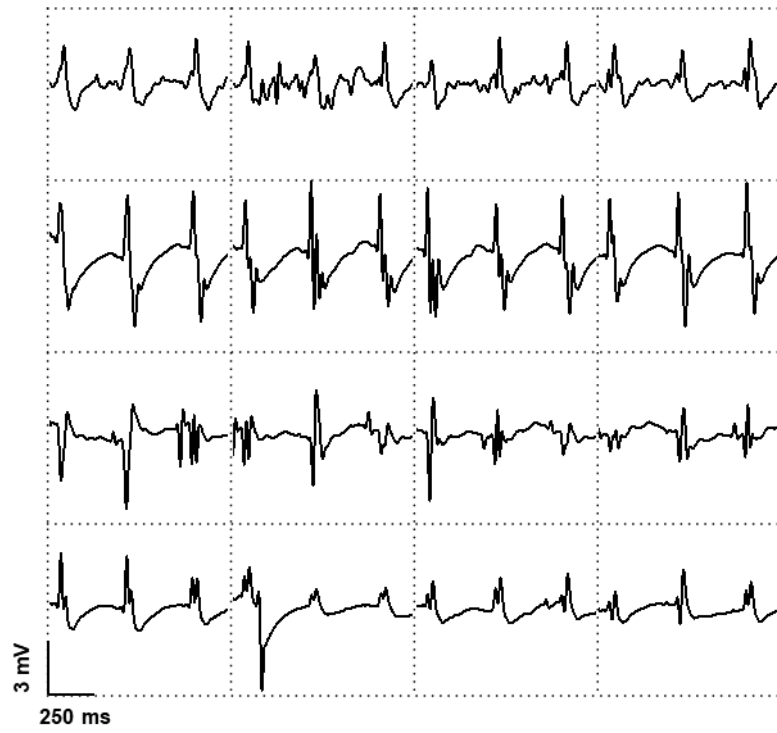
Supplementary Fig. 22. Time-dependent photocurrent response of the pure P3-based photodetector at 0% strain.



Supplementary Fig. 23. a, Schematic connection of the human subject, rubbery transistor, and data acquisition system. **b,** Measured ECG signals.



Supplementary Fig. 24. Power spectral density of ECG signals. The blue region indicates the relevant ECG frequencies, and the red region indicates the frequencies in the noise floor.



Supplementary Fig. 25. ECG traces from all 16 sensing nodes.

Supplementary Table 1. Electrical performances of the LASM-1 thin film-based transistor.

Maximum mobility (cm²V⁻¹s⁻¹)	Average mobility (cm²V⁻¹s⁻¹)	V_{th} (V)	I_{on} / I_{off}
1.15	0.9	2.65	2.76×10 ⁴

Supplementary Table 2. Comparison of rubbery CT inverter with reported stretchable inverter.

Materials	Gain without strain	Gain at applied strain	Gain Decreased percentage	Complementary inverter	Ref.
LPSM film	5.2	3.2 (50%)	38%	Yes	This work
P3HT	5.1	3.8 (60%)	25%	No	1
Si	1.3	~ (10%)	-	No	2

Supplementary Table 3. Comparison of fully rubbery photodetector with the reported stretchable photodetector.

Materials	ON/OFF ratio without strain	ON/OFF ratio at applied strain	ON/OFF ratio Decreased	Ref.
LPSM film	27	22 (50%)	18.5%	This work
ZnO	188	~145 (50%)	22.9%	3
crumpled graphene	--	--	90%	4
GaN nanowire	--	--	13%	5
CH ₃ NH ₃ PbI ₃ microwires	2.71	~0.9 (50%)	70%	6
Graphene	10	2 (25%)	80%	7

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6. Cho KG, et al. Printable carbon nanotube-based elastic conductors for fully-printed sub-1 V stretchable electrolyte-gated transistors and inverters. *Journal of Materials Chemistry C* 8, 3639-3645 (2020).
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