Electronic Supplementary Information (ESI)

Photoresponsive multifunctional anisotropic conductive hydrogel membrane for human motion detection, information encryption and transmission

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Experimental Section

Chemicals

$Co(Ac)_2$ (analytical grade, CAS: 6147-53-1), $Fe(NO_3)_3$ (analytical grade, CAS: 7782-61-8), NaOH (analytical grade, CAS: 1310-73-2), HNO_3 (analytical grade CAS: 7697-37-2), 2,7-dibromo-fluorenone (DF) (analytical grade CAS: 16432-81-8), gelatin (GE, biochemical reagents, CAS: 9000-70-8), 99.5 % hexafluoroisopropanol (HPIF, CAS: 920-66-1), phosphate buffer liquid (PBS), 50 % glutaraldehyde (GA, CAS: 111-30-8), and anhydrous ethanol are purchased from Aladdin Reagent Co. in Shanghai, China. Deionized water (DI) is prepared in the laboratory.

Preparation of $CoFe_2O_4$ NPs

$CoFe_2O_4$ nanoparticles are synthesized by coprecipitation method. The steps are as follows: Dissolve 20 g of NaOH in 300 mL of deionized water and boil at 120 °C. 6.22 g $Co(Ac)_2$ and 20.2 g $Fe(NO_3)_3$ are dissolved in 25 mL DI and heated to 60 ℃. Then the mixed liquid is poured into boiling NaOH liquid and stirred continuously at 85 ℃ for 1 h. HNO_3 liquid (DI:HNO_3=1:1) is added into the above mixed liquid, then a small amount of drops is used to adjust the pH value to 4.8, and keep the temperature unchanged during the process to obtain $CoFe_2O_4$ NPs. The obtained $CoFe_2O_4$ NPs is washed three times with deionized water and ethanol, respectively. Finally, the precipitates are dried in an oven at 60

℃ for 48 h to obtain $CoFe_2O_4$ NPs.

Preparation of spinning liquids

The luminescent conductive side of [$CoFe_2O_4$/GE]//[DF/GE] Janus nanobelts array membrane (defined as JNAM) is prepared by spinning liquid I. The process is as follows: DF powder is added to the mixture of HPIF and GE in different proportions, and spinning liquid I is obtained by stirring for 3 h. The magnetic insulating side of Janus nanobelts of JNAM is prepared by spinning liquid II. The magnetic spinning liquid II is prepared by adding $CoFe_2O_4$ powder to HPIF and GE mixtures in different ratios and stirring for 3 hours. The actual composition of spinning liquid I and spinning liquid II is shown in Tables S1 and S2.

Table S1 Components of spinning liquid I

Spinning liquid I	GE/DF/wt %	DF/g	GE/g	HPIF/mL
I_a	5	0.1	2	20
I_b	10	0.2	2	20
I_c	15	0.3	2	20
I_d	20	0.4	2	20

Table S2 Components of spinning liquid II

Spinning liquid II	GE/$CoFe_2O_4$/wt %	$CoFe_2O_4$/g	GE/g	HPIF/mL
II_a	30	0.6	2	20
II_b	60	1.2	2	20
II_c	90	1.8	2	20
II_d	120	2.4	2	20

Characterization techniques

After freeze-drying in a freeze dryer, the sample was cut into 0.1×0.1 cm and attached to the sample stage. Subsequently, the sample was subjected to gold sputtering treatment and its morphology was observed under a scanning electron microscope (SEM, JSM-7610F). An energy dispersive spectrometer (EDS, Oxford X-Max N80) is used to analyze the composition and distribution of elements in the samples. The dispersion of the nanoribbon functional fillers was observed using an optical microscope (OM, BT-1600). The sample was freeze-dried in a freeze dryer (STANTZ-12N) and ground into powder. It was analyzed using an FTIR spectrometer (Nicolet, IS5) in diffuse reflectance mode and infrared spectroscopy in the range of 4000 to 500 cm^{-1}, with a resolution of 4 cm^{-1}. Thermal stability analysis of the sample was conducted using a thermogravimetric analyzer (Q5000IR). A 99.5% alumina dry crucible served as the

sample cell, with testing performed at a heating rate of 10 °C/min and cooling rate of 20 °C/min. A luminescence spectrometer (Hitachi F7000) is used to analyze the luminescence properties of the samples. A microcomputer-controlled electronic universal testing machine (WDW-20 kN) is used for stress-strain testing of the products. The photocurrent of the samples is measured by electrochemical workstation CHI760D with a three electrode system and PLSSXE300/300UV xenon lamp. JNHAM is attached to the conductive side of the conductive glass as the working electrode, while a carbon rod and a saturated calomel electrode are used as the counter electrode and reference electrode, respectively. The voltage is fixed at 5 V, and a xenon lamp is used to irradiate the surface of JNHAM while obtaining photocurrent. The light power density of the xenon lamp is achieved by directly controlling the electrical power supplied to the lamp. The lamp's operating current or power is set via a computer software interface. A TH2810B+ digital bridge, a silicone heating pad and a PLSSXE300/300UV type xenon lamp are used to test the resistance change of the samples. The PHI 5000 Versa Probe X-ray photoelectron spectrometer (XPS) is used to analyze quantitatively the composition of the elements and the valence state of the elements in the samples. The XPS is produced by ULVCA-PHI Company and mono X-ray source is Al K excitation, the full spectrum scan ranged from 0 eV to 1200 eV. All the above measurements are performed at room temperature.

Results and Discussion

Morphological and Structural Analysis

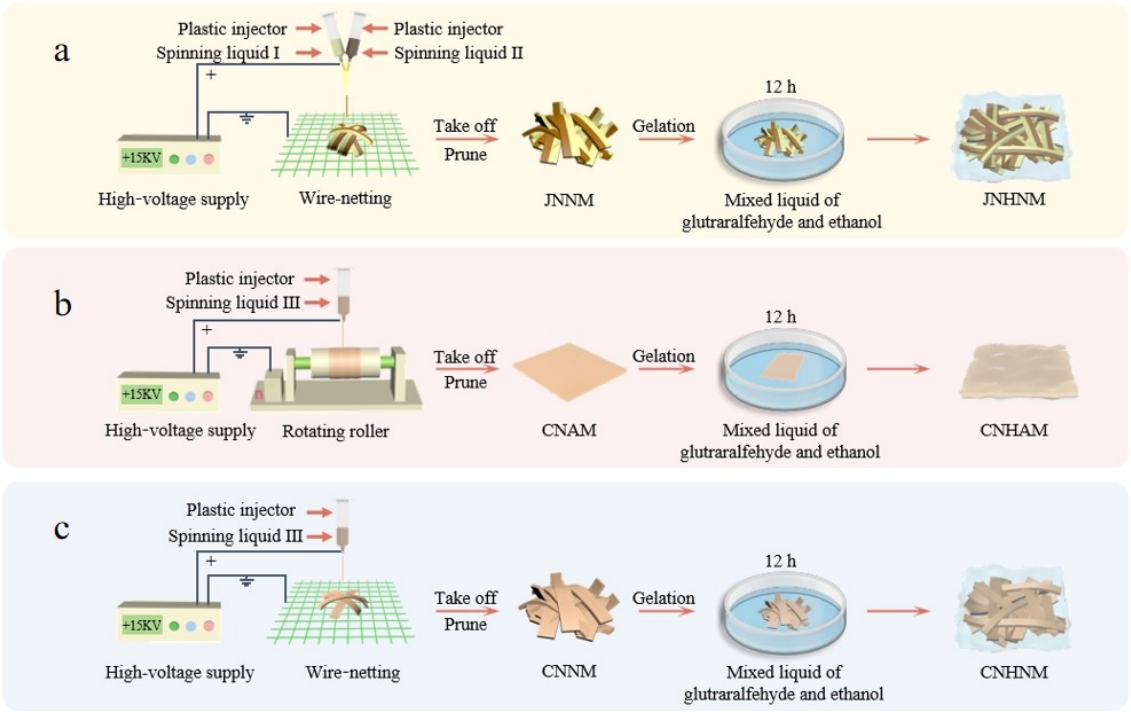

Figure S1 Schematic drawing of hydrogel prepared by electrospinning method: (a) JNHNM, (b) CNHAM and (c) CNHNM

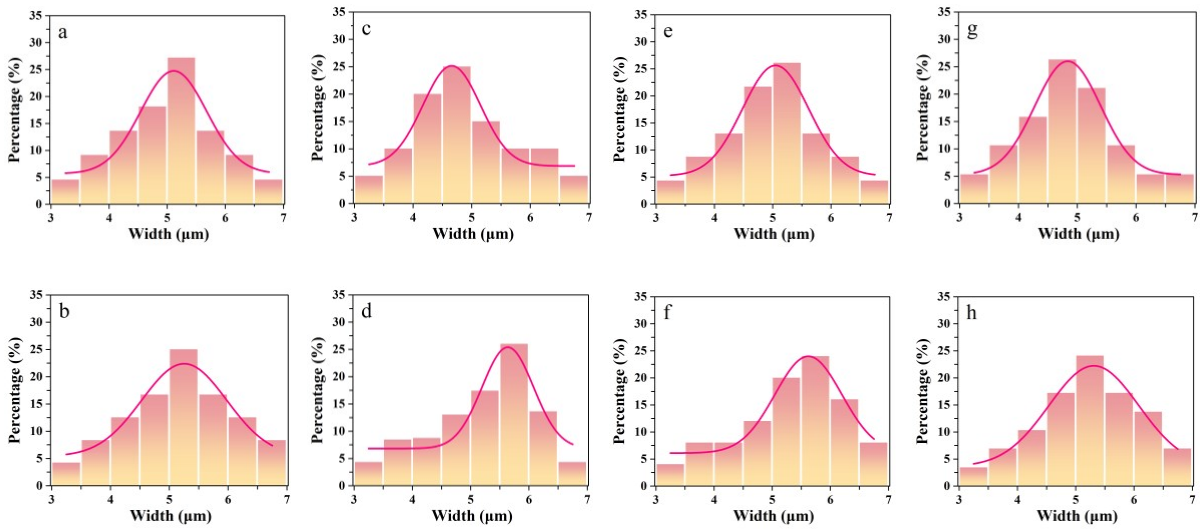

Figure S2 Histograms of nanobelts width distribution in JNAM (a), JNHAM (b), JNNM (c), JNHNM (d), CNAM (e), CNHAM (f), CNNM (g) and CNHNM (h)

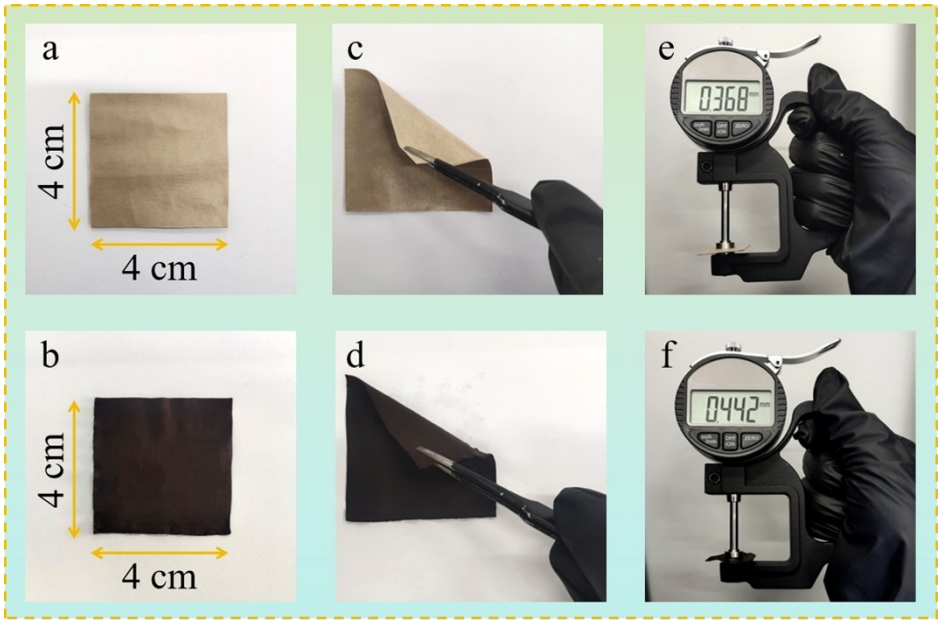

Figure S3 Physical photographs of flat JNAM (a) and JNHAM (b), curled JNAM (c) and JNHAM (d), hickness test charts of JNAM (e) and JNHAM (f)

Characterization of Chemical Structure

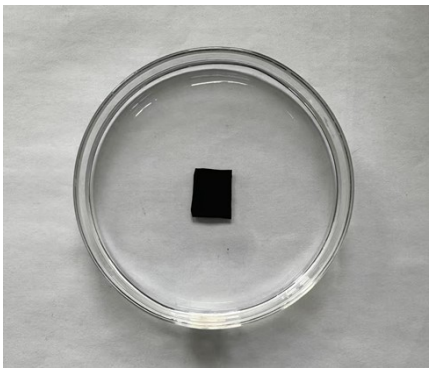

Figure S4 Physical image of JNHAM immersed in deionized water

Luminescence Performance Analysis

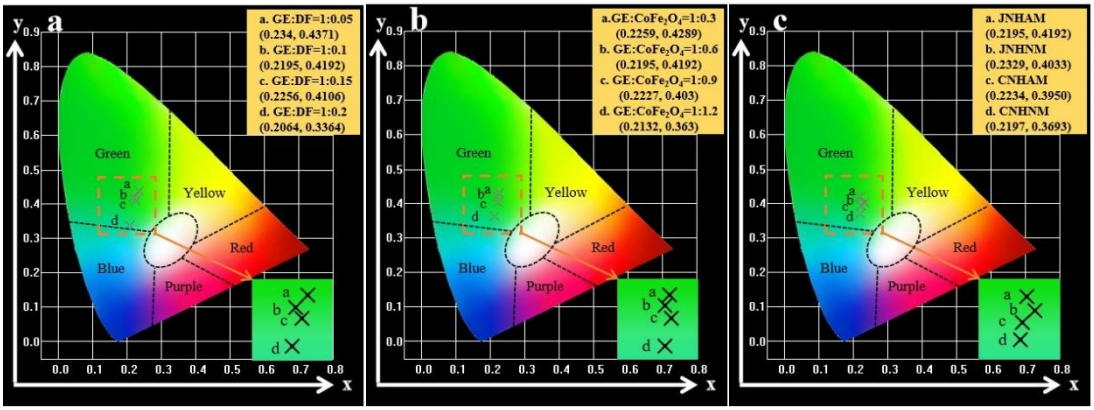

Figure S5 CIE chromaticity coordinate plots of JNHAM with different DF (a) and $CoFe_2O_4$ (b) mass and the control samples (c) under 268 nm UV excitation

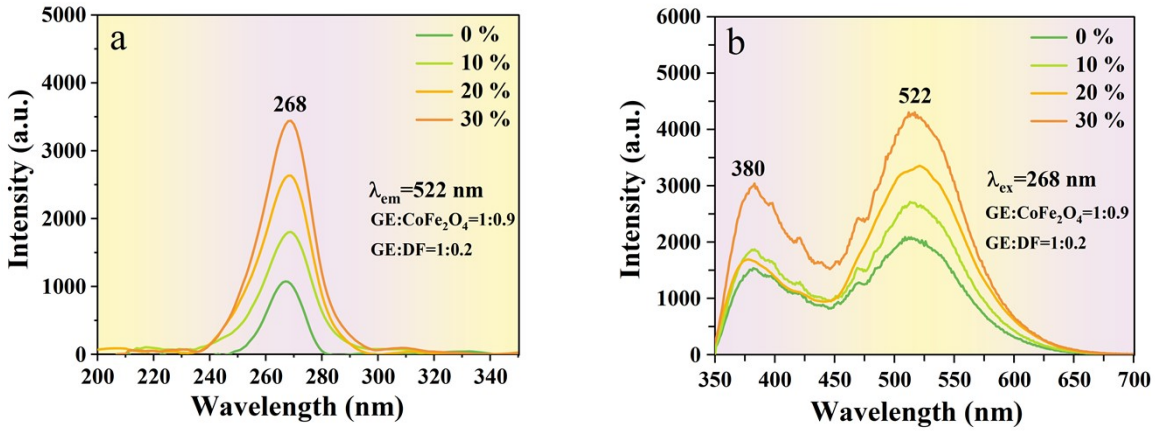

Figure S6 (a, b) Excitation and emission spectra of JNHAM under different tensile strains at fixed GE/$CoFe_2O_4$ and GE/DF contents

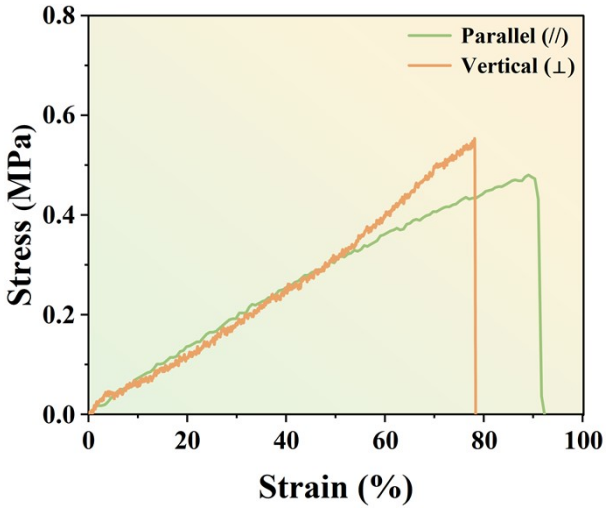

Figure S7 Stress-strain curves of JNHAM without $CoFe_2O_4$ NPs in parallel and perpendicular tensile directions

Conductivity analysis

Table S3 Photoelectric response of JNHAM and control samples with different proportions at optical power density of 1500 mW/cm^2

Samples	PC_A (μA)	DC_A (μA)	PC_B (μA)	DC_B (μA)	PG_A	PG_B
JNHAM (GE:DF=1:0.05 GE:$CoFe_2O_4$=1:0.9)	0.138	0.002	0.003	0.001	2.76×10^{-8}	6×10^{-10}
JNHAM (GE:DF=1:0.1 GE:$CoFe_2O_4$=1:0.9)	0.202	0.003	0.003	0.001	4.04×10^{-8}	6×10^{-10}
JNHAM (GE:DF=1:0.15 GE:$CoFe_2O_4$=1:0.9)	0.25	0.003	0.004	0.002	5.0×10^{-8}	8×10^{-10}
JNHAM (GE:DF=1:0.2 GE:$CoFe_2O_4$=1:0.9)	0.345	0.002	0.003	0.003	6.9×10^{-8}	6×10^{-10}
JNHAM (GE:DF=1:0.1 GE:$CoFe_2O_4$=1:0.3)	0.192	0.002	0.003	0.001	3.84×10^{-8}	6×10^{-10}
JNHAM (GE:DF=1:0.1 GE:$CoFe_2O_4$=1:0.6)	0.189	0.002	0.002	0.001	3.78×10^{-8}	4×10^{-10}
JNHAM (GE:DF=1:0.1 GE:$CoFe_2O_4$=1:1.2)	0.169	0.008	0.003	0.002	3.38×10^{-8}	6×10^{-9}
JNHNM (GE:DF=1:0.1 GE:$CoFe_2O_4$=1:0.9)	0.106	0.007	0.14	0.002	2.12×10^{-8}	2.8×10^{-8}
CNHAM (GE:DF=1:0.1 GE:$CoFe_2O_4$=1:0.9)	0.163	0.005	0.007	0.002	3.26×10^{-8}	1.4×10^{-9}

CNHNM (GE:DF=1:0.1 GE:$CoFe_2O_4$=1:0.9)	0.221	0.006	0.082	0.003	4.42×10^{-8}	1.64×10^{-8}

Table S4 Conductivity anisotropy levels of JNHAM and control samples at different proportions with optical power density of 1500 mW/cm^2

Samples	PC_A/DC_A	PC_B/DC_B	PC_A/PC_B	Degree of anisotropy	DC_A/DC_B	Degree of anisotropy
JNHAM (GE:DF=1:0.05 GE:$CoFe_2O_4$=1:0.9)	69	3	46	Medium	2	—
JNHAM (GE:DF=1:0.1 GE:$CoFe_2O_4$=1:0.9)	67.3	3	67.3	Medium	3	—
JNHAM (GE:DF=1:0.15 GE:$CoFe_2O_4$=1:0.9)	83.3	2	62.5	Medium	1.5	—
JNHAM (GE:DF=1:0.2 GE:$CoFe_2O_4$=1:0.9)	172.5	1	115	Medium	0.667	—
JNHAM (GE:DF=1:0.1 GE:$CoFe_2O_4$=1:0.3)	96	3	64	Medium	2	—
JNHAM (GE:DF=1:0.1 GE:$CoFe_2O_4$=1:0.6)	94.5	2	94.5	Strong	2	—
JNHAM (GE:DF=1:0.1 GE:$CoFe_2O_4$=1:1.2)	21.13	1.5	56.3	Medium	4	—
JNHNM (GE:DF=1:0.1	15.14	70	0.757	—	3.5	—

GE:$CoFe_2O_4$=1:0.9)						
CNHAM						
(GE:DF=1:0.1	32.6	3.5	23.28	Weak	2.5	—
GE:$CoFe_2O_4$=1:0.9)						
CNHNM						
(GE:DF=1:0.1	36.83	27.3	2.69	—	3	—
GE:$CoFe_2O_4$=1:0.9)						

Table S5 Different optical power density photoelectric response of the JNHAM

Lighting power (mW/cm^2)	PC_A (μA)	DC_A (μA)	PC_B (μA)	DC_B (μA)	PG_A	PG_B
1300	0.423	0.006	0.016	0.008	8.46×10^{-8}	3.2×10^{-9}
1500	0.545	0.005	0.017	0.006	1.09×10^{-7}	1.4×10^{-9}
1700	0.794	0.005	0.016	0.004	1.59×10^{-7}	3.4×10^{-9}

Table S6 Conductivity anisotropy levels of JNHAM at various optical power densities

Lighting power (mW/cm^2)	PC_A/DC_A	PC_B/DC_B	PC_A/PC_B	Degree of anisotropy	DC_A/DC_B	Degree of anisotropy
1300	70.5	2	26.437	Medium	0.75	—
1500	109	2.83	32.059	Medium	0.8333	—
1700	158.8	4	49.625	Medium	1.25	—