

## Supplementary information

### **Gellan gum-based ionic conductive hydrogel with self-healing capability, piezoionicity and ionic thermoelectricity as flexible sensors**

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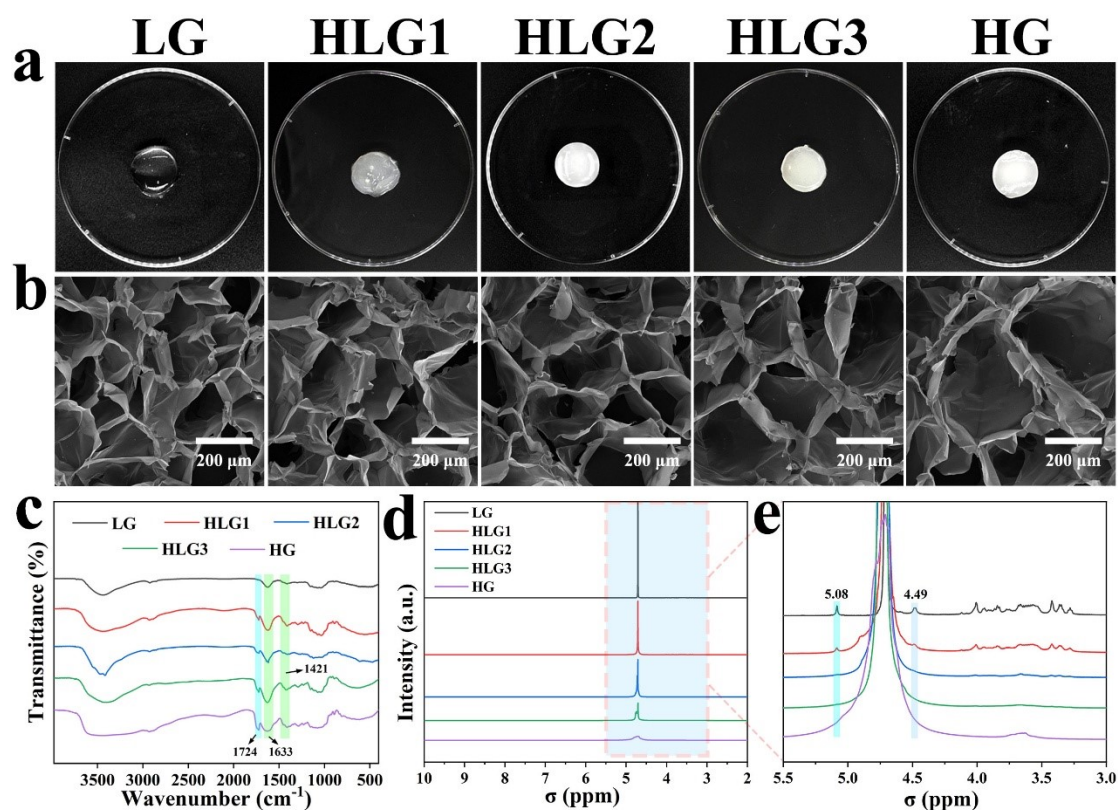
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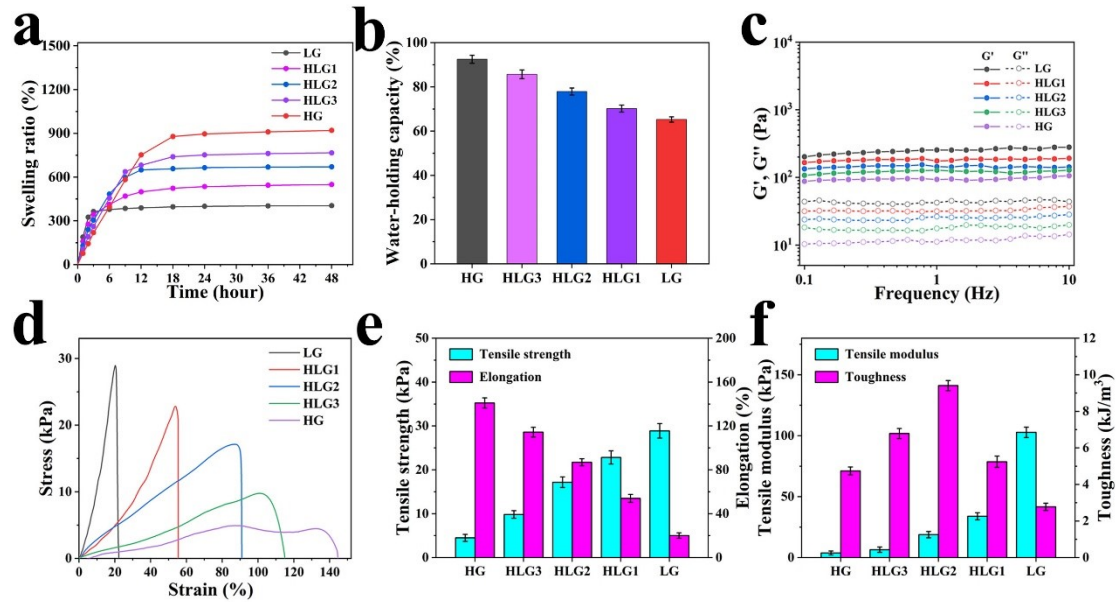


**Fig. S1.** Digital photos (a), SEM images (b), FTIR spectrum (c),  $^1\text{H-NMR}$  spectrum (d) and enlarged spectrum (e).

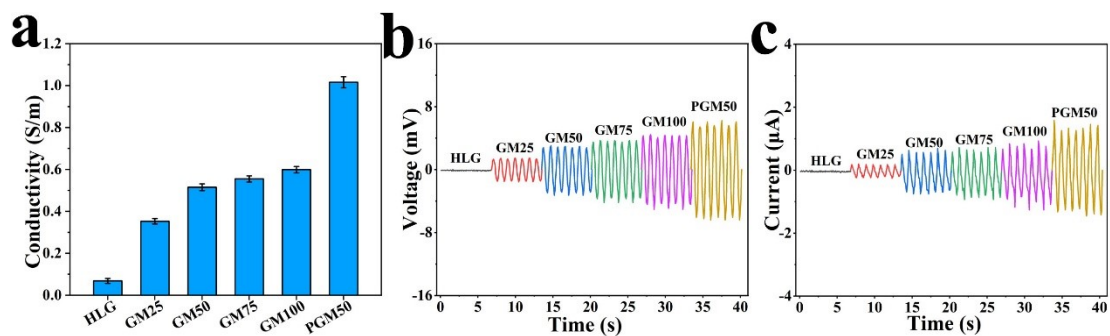
Fig. S1a shows the digital photos of different samples of HGL. LG is colorless and transparent, while HG is white and translucent. As the HG ratio increases, transparency of HGL decreases. SEM images (Fig. S1b) reveal a 3-D network structure with uniformly distributed pores of all samples, and the pore size increases of HGL with HG content increasing. FTIR (Fig. S1c) shows that all samples exhibit the characteristic peaks at 3442, 1633, 1421, and 1100  $\text{cm}^{-1}$ , and peak intensity of C=O group at 1724  $\text{cm}^{-1}$  increases with the increase of HG content.

The  $^1\text{H-NMR}$  spectra (Fig. S1d, e) shows that the peak intensity of sugar ring proton at 4.71 ppm decreases and broadens, indicating steric hindrance from HG. Fig. S2a presents that the swelling ratio of HGL increases with HG ratio increasing due to high hydrophilicity of HG. Fig. S2b shows that the water-holding capacity of the samples increases with the HG content increasing. Fig. S2c shows rheological curves, where  $G'$  is greater than  $G''$  for all samples, but both decrease with HG content increasing. Fig.

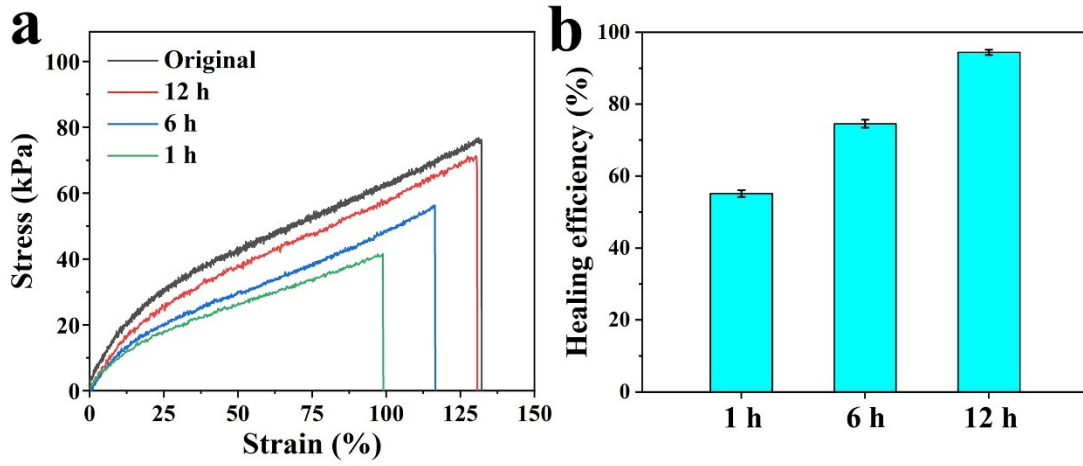
S2d, e, f show that the tensile strength and modulus decrease, while elongation at break increases with HG content increasing. Fig. S2f shows that the toughness of the samples initially increases, then decreases, and HLG2 exhibits the highest toughness ( $7.6 \text{ kJ/m}^3$ ), indicating the optimal flexibility.



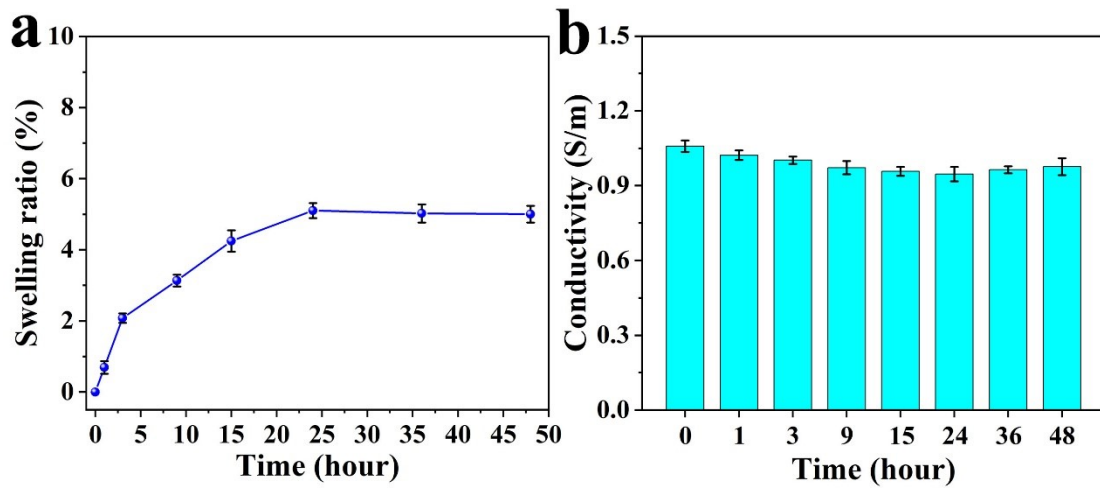
**Fig.S2.** Swelling ratio (a) and water-holding capacity (b) of different samples; Frequency-sweep rheological curves of  $G'$  and  $G''$  (c); Tensile stress-strain curves (d), Tensile strength and elongation (e) and Tensile modulus and toughness (f).



**Fig. S3.** Conductivity (a), Open-circuit voltage (b) and Short-circuit current (c) of different samples.



**Fig.S4** Tensile stress-strain curves (a) and self-healing efficiency (b) of PGM50 with the different healing time.



**Fig.S5** Swelling ratio (a) and conductivity (b) of PGM50 after immersion in water for different time.

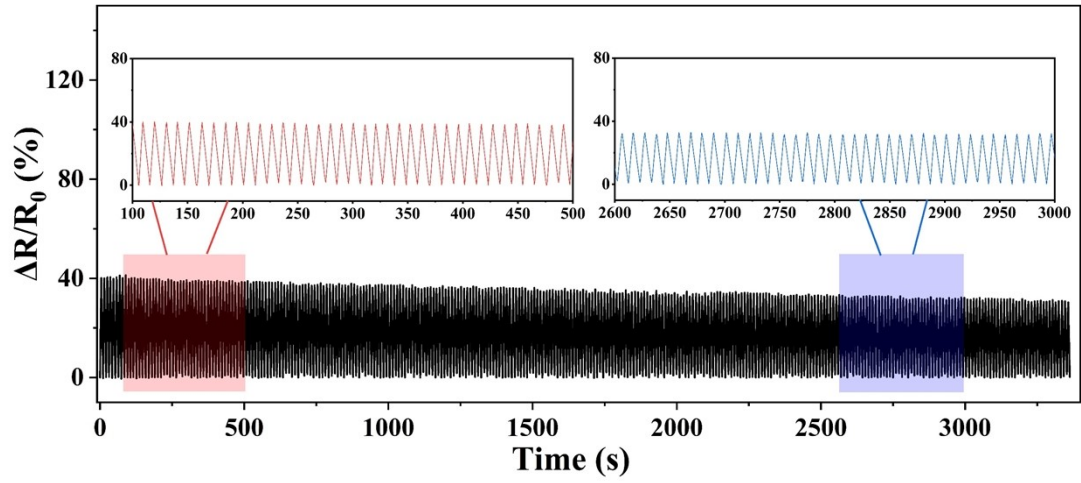


Fig.S6 Stability of the PGM50 piezoresistive sensor.

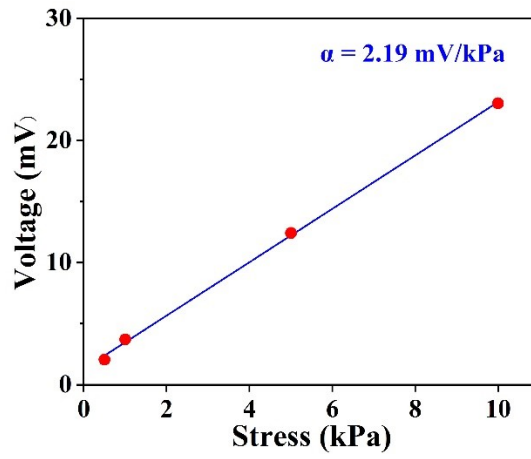


Fig.S7 Piezoionic coefficient of the PGM50 piezoionic sensor.

Table S1 Tensile strength and elongation of PGM50 and recent ionic hydrogels

Material	Tensile strength /Elongation	Reference
Phytic acid /Gellan gum /MnCl <sub>2</sub> ionic hydrogel (PGM50)	68.7 kPa /132.6%	This work
Cellulose/NaOH ionic hydrogels (CIHs)	49 kPa /120.9%	S1
Poly (sulfobetaine methacrylate)/ Calcium alginate ionic hydrogel (BIH)	12.3 kPa /175%	S2
Gelatin/Tannic acid/Dialdehyde-β- cyclodextrin/Borax hydrogel (GT <sub>5</sub> -DACD <sub>2</sub> -B)	41 kPa /142.6%	S3
Oxidized alginate /Gelatin/Borax/CaCl <sub>2</sub> hydrogel (CaAG-30m)	23.6 kPa /204%	S4

Table S2 Compressive strength and compressibility of PGM50 and recent ionic hydrogels

Material	Compressive strength /Compressibility	Reference
Phytic acid /Gellan gum /MnCl <sub>2</sub> ionic hydrogel (PGM50)	429.3 kPa /64.7%	This work
Methacrylate-Kappa-carrageenan /Dopamine functionalized graphene oxide/KCl hydrogel (KaMA-GOPD)	167.3 kPa /60%	S5
Silk sericin-g-Glycidyl methacrylate /Phenyl (2,4,6-trimethylbenzoyl) lithium phosphate ionic hydrogel (SS-g-GMA30%)	70.03 kPa /67.09%	S6
Borax-functionalized oxidized chondroitin sulphate /Polypyrrole /Gelatin hydrogel (BOCPG)	239 kPa /76.5%	S7
Poly dopamine methacrylamide- methacrylatoethyl trimethyl ammonium chloride-acrylic acid /cellulose nanofiber ionic hydrogels (PDDA/CNF)	260.9 kPa /76%	S8

Table S3 The  $G'$  and  $n_e$  values for HLG, GM50 and PGM50

<b>Material</b>	<b><math>G'</math>(Pa)</b>	<b><math>n_e</math> (mol/m<sup>3</sup>)</b>
HLG	141	0.06
GM50	3068	1.24
PGM50	9785	3.95

Table S4 GF of PGM50 and recent hydrogel flexible sensors

<b>Material</b>	<b>GF</b>	<b>Reference</b>
Phytic acid /Gellan gum /MnCl <sub>2</sub> ionic hydrogel (PGM50)	1.752	This work
Agar /Borax /MXene /NaOH conductive hydrogel (Agar/Borax/MXene CH)	1.520	S9
Poly 1-methyl-3-(4-vinylbenzyl)imidazolium chloride-r-sodium 2-acrylamino-2-methylpropanesulfonate ionic conductive hydrogel (PMVIC-r-SAMS)	1.140	S10
P(AM-co-SBMA) /Waterborne polyurethane /Zn <sup>2+</sup> (PASU-Zn)	0.060	S11
PVA /Xanthan Gum /Borax hydrogel (PVA /XTG /Borax)	0.56	S12
Cellulose /Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> /LiOH /Urea /AgNW hydrogel (X-cel-OH)	0.71	S13

Table S5 Piezoionic coefficient of PGM50 and recent piezoionic hydrogels

<b>Material</b>	<b>Piezoionic coefficient (mV/kPa)</b>	<b>Reference</b>
Phytic acid /Gellan gum /MnCl <sub>2</sub> ionic hydrogel (PGM50)	2.19	This work
Poly(acrylic acid)/Lithium chloride hydrogels (PAA/LiCl)	0.043	S14
SnSe-Hydrogel Composites	1.78	S15
Poly(acrylamide-co-poly(ethylene glycol) diacrylate)/NaCl (P(AM-co-PEGDA))	0.013	S16

## References

- S1. R. Tong, G. Chen, D. Pan, H. Qi, R. a. Li, J. Tian, F. Lu and M. He, *Biomacromolecules*, 2019, **20**, 2096-2104.
- S2. B. Chen, R. Yu, J. Wang, Y. Feng, Y. Zhang, Y. Mao, C. Shan and X. Wang, *Advanced Functional Materials*, 2025, **n/a**, e27495.
- S3. M. Li, S. Wang, Y. Li, X. Meng, Y. Wei, Y. Wang, Y. Chen, Y. Xiao and Y. Cheng, *ACS Applied Materials & Interfaces*, 2024, **16**, 51618-51629.
- S4. X. Zhang, K. Wang, J. Hu, Y. Zhang, Y. Dai and F. Xia, *Journal of Materials Chemistry A*, 2020, **8**, 25390-25401.
- S5. H. Mokhtari, M. Kharaziha, F. Karimzadeh and S. Tavakoli, *Carbohydrate Polymers*, 2019, **214**, 234-249.
- S6. T. Zha, W. Zhou, J. Chen, Y. Liu, Y. Liu, X. Wang, X. Li, B. Li, Q. Han and S. Du, *Polymer*, 2026, **342**, 129362.
- S7. Y. Luo, L. Fan, C. Liu, H. Wen, S. Wang, P. Guan, D. Chen, C. Ning, L. Zhou and G. Tan, *Bioactive Materials*, 2022, **7**, 98-111.
- S8. J. Wei, X. Zhang, F. Wang, Y. Shao, W.-B. Zhang and H. Wu, *Compos. Sci. Technol.*, 2023, **231**, 109793.
- S9. Z. Nie, K. Peng, L. Lin, J. Yang, Z. Cheng, Q. Gan, Y. Chen and C. Feng, *Chemical Engineering Journal*, 2023, **454**, 139843.
- S10. B. Zhang, X. Zhang, H. Song, D. H. Nguyen, C. Zhang and T. Liu, *ACS Applied Materials & Interfaces*, 2022, **14**, 32551-32560.
- S11. H. Wang, X. Li, Y. Ji, J. Xu, Z. Ye, S. Wang and X. Du, *Journal of Materials Chemistry B*, 2022, **10**, 2933-2943.
- S12. Y. Xu and X. Maimaitiyiming, *International Journal of Biological Macromolecules*, 2024, **282**, 136972.
- S13. X. Feng, C. Xing, C. Wang, Y. Tian, S. Shang, H. Liu, X. Huang, J. Jiang, Z. Song and H. Zhang, *International Journal of Biological Macromolecules*, 2024, **267**, 131536.
- S14. J. Dai, Y. Xue, X. Chen, Z. Cao, L. Wang, J. Zhang, Y. Zhou, Y. Hu, W. Zhou, W. Tang, X.-Y. Kong, B. Tu, J. Liu and K. Xiao, *Device*, 2024, **2**, 100436.
- S15. F. Li, X. Cai, G. Liu, H. Xu and W. Chen, *Advanced Functional Materials*, 2023, **33**, 2300701.
- S16. B. Ma, K. Huang, G. Chen, Y. Tian, N. Jiang, C. Zhao and H. Liu, *Soft Science*, 2024, **4**, 8.