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Self-healable conductive supramolecular gels for the applications of multi-functional sensors and self-powered energy harvesting devices

陽明交大 NYCU

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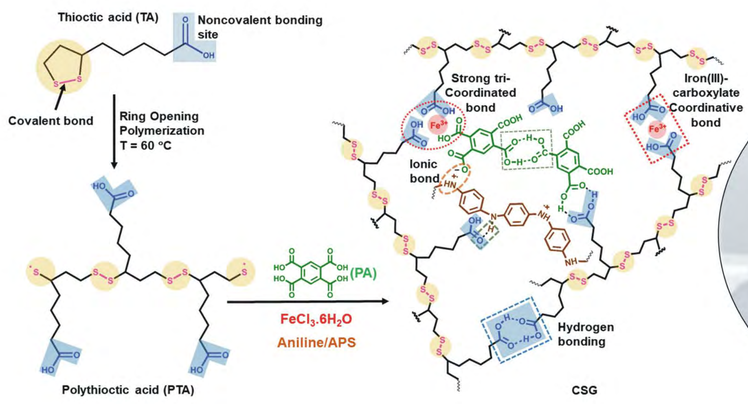
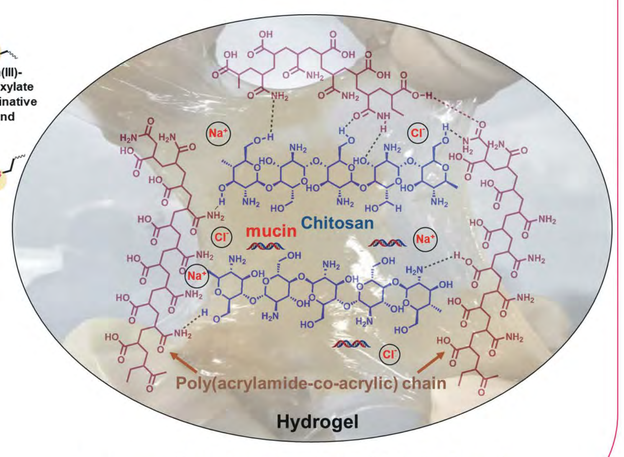
Abstract

This research focuses on the synthesis and fabrication of novel supramolecular gels constructed by interactions of reversible physical bonds for multifunctional sensors and energy harvesting application. Using human motion detections, adhesive applications, and injectable writings, we have demonstrated the performance of supramolecular organogel-based sensors. We have also developed a self-healing and stretchable gel-based triboelectric nanogenerator (TENG) with a wide operating temperature range of -40 to 80 ° C. Additionally, a self-healing hydrogel-based artificial bioelectronic tongue (E-tongue) is introduced with the capability of detecting astringent and bitter substances with remarkable sensitivity even at -5 ° C.

Synthesis of conductive self-healable gels

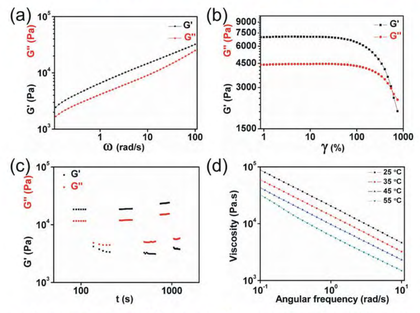


Schematic synthetic route of conductive self-healable organogels

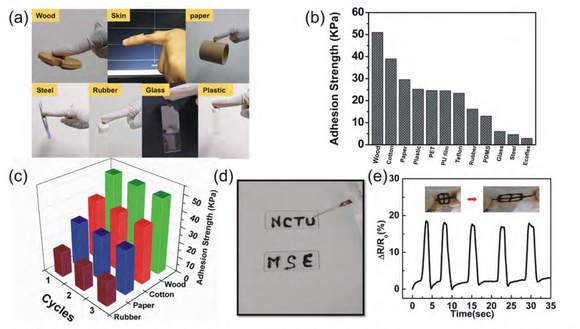


Structure of conductive self-healable hydrogel

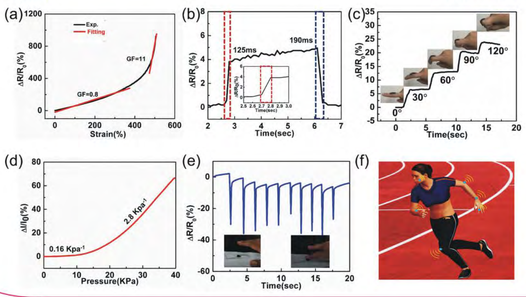
Conductive self-healable organogels as tactile sensor



Characterizations of CSG1.0Fe (a) Variation of storage (*G'*) and loss (*G''*) moduli as a function of frequency at 1% angular strain. (b) Strain sweep rheology test at a fixed angular frequency of 1 rad/s. (c) *G'* and *G''* variations under continuous strain sweep variation with alternative small oscillation (1% strain) and large oscillation (800% strain) forces. Angular frequency = 10 rad/s. (d) Temperature dependent rheology.

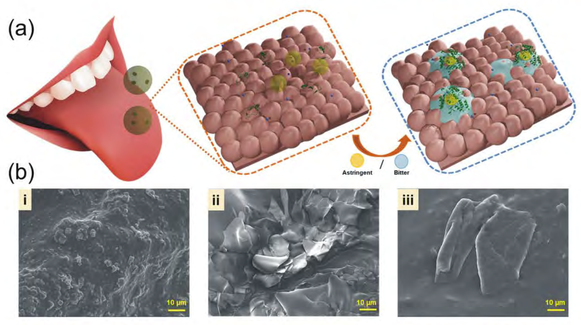


Applications of CSGs. (a) Photographs of the conductive gel CSG1.0Fe adhered to different substrates. (b) Maximum shear adhesion strengths of the conductive gel CSG1.0Fe adhered to different substrates. (c) Repetitive adhesion tests of CSG1.0Fe for 3 cycles on 4 different substrates (rubber, paper, cotton, and wood). (d) Optical image of injectable CSG1.0Fe writing on glass substrates. (e) Repetitive piezoresistive responses of a patterned injectable CSG. Inset: patterned CSG over an Ecoflex substrate.

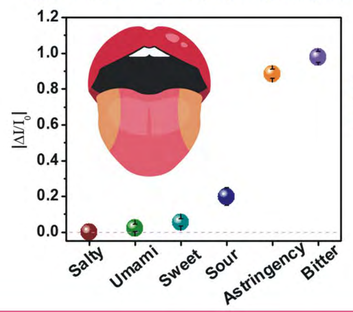


Electro-mechanical measurements of CSG1.0Fe. (a) Strain-dependent relative change in resistance. (b) Response and recovery time of a sensor at a strain of 3%. (c) Stepwise responses of a sensor with relative changes in resistance to increase the angles of finger bending. (d) Relative change in current *vs.* applied pressure. (e) Time-dependent and repetitive relative changes in resistance of a pressure sensor under cyclic manual pressing actions. (f) Schematic of motion detection for various body parts by conductive gel strain sensors.

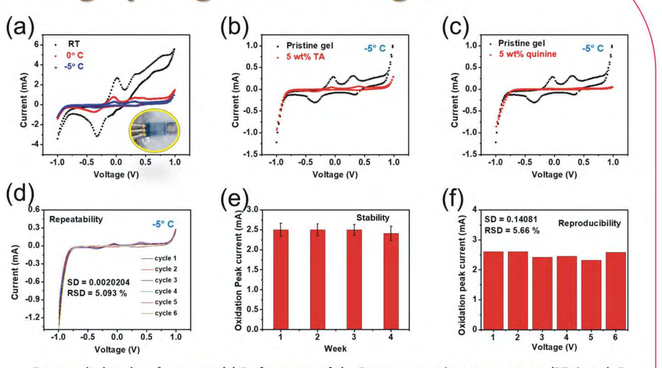
Self-healable and anti-freezing hydrogels as E-tongue



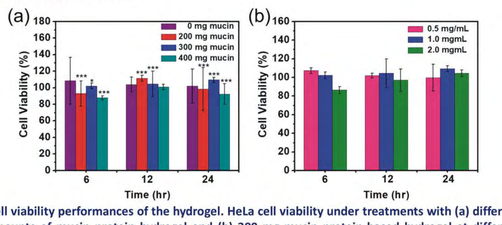
E-tongue sensing mechanism. (a) Schematic illustration for the sensing mechanism of E-tongue. (b) Scanning electron microscopy (SEM) images of E-tongue hydrogels i) without tastants, in contact with ii) 1 wt% tannic acid (TA), and iii) 1 wt% quinine sulfate (QS).



Selective sensing performance of the artificial E-tongue in contact with five basic tastes and astringency measured after 60 s; all tastants were 5 wt%.

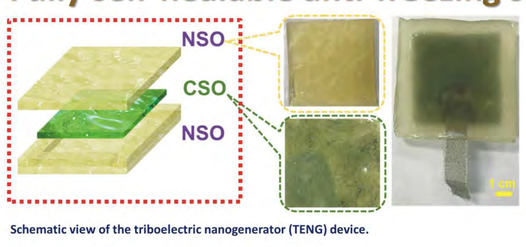


E-tongue hydrogel performances. (a) Performances of the E-tongue at various temperatures (RT, 0, and -5 °C). (b) Astringency detection of the E-tongue at -5 °C in contact with 5 wt% of TA. (c) Bitterness detection of the E-tongue at -5 °C in contact with 5 wt% of QS. (d) Repeatability of the E-tongue sensing at -5 °C in contact with 5 wt% of TA. (e) Stability of the E-tongue hydrogel; Error bar = SD (n=3). (f) Reproducibility of the E-tongue performances.

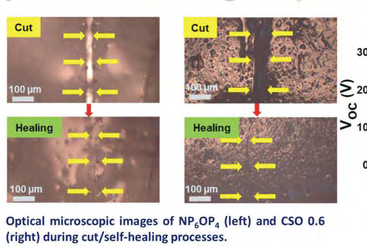


Cell viability performances of the hydrogel. HeLa cell viability under treatments with (a) different amounts of mucin protein hydrogel and (b) 300 mg mucin protein-based hydrogel at different concentrations. The data are reported as the mean ± SD, (*, P < 0.05; **, P < 0.01; ***, P < 0.001).

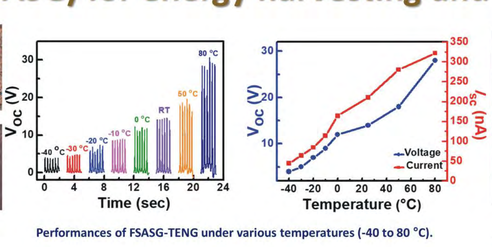
Fully self-healable anti-freezing supramolecular gels (FSASG) for energy harvesting and wearable electronics



Schematic view of the triboelectric nanogenerator (TENG) device.

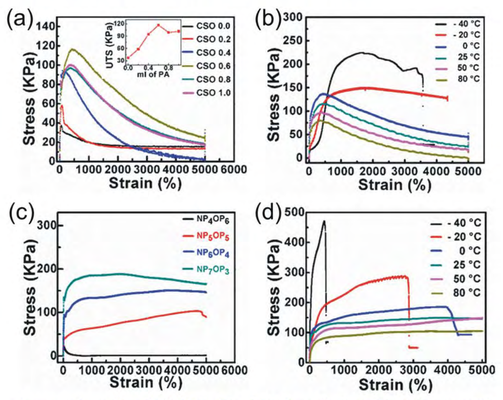


Optical microscopic images of NP_6OP_4 (left) and CSO 0.6 (right) during cut/self-healing processes.

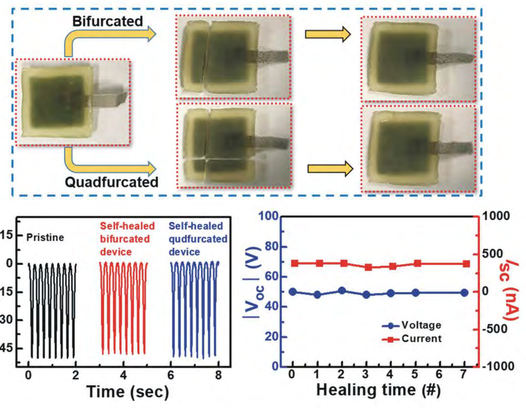


Performances of FSASG-TENG under various temperatures (-40 to 80 °C).

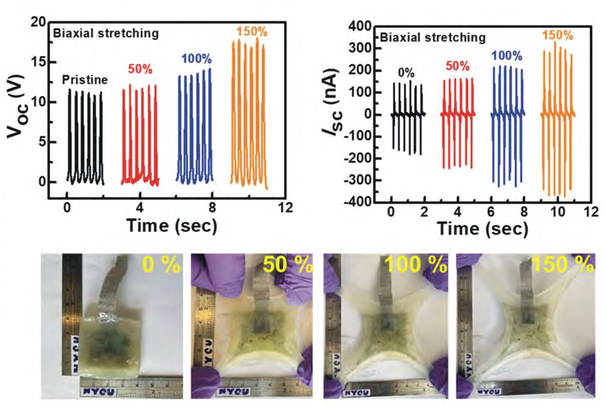
Applications of FSASG-TENG to drive electronic watch and calculator



Stress-strain profiles of (a) CSO X_{PA} (X_{PA} =0.0-1.0): conductive self-healable organogels (CSOs) with different amounts (0.0-1.0 ml) of phytic acid (PA) and (b) CSO 0.6 at different temperatures. Stress-strain profiles of c) NP_xOP_{10-x} (x=4-7): nonconductive self-healable organogels (NSOs) and (d) NP_6OP_4 at different temperatures.



Performances of FSASG-TENG after bifurcated and quadfurcated self-healing.



Performances of FSASG-TENG after various biaxial stretching.

Conclusion

In this work, we synthesized various conductive and non-conductive self-healable supramolecular gels for the applications of sensors and energy harvesting devices that can be useful at all environments. These outstanding results provide a promising door for next generation wearable electronics and humanoid robots.

Selected Journal Publications:

1. **Amir Khan,** Ravinder Reddy Kisannagar, Chinmayananda Gouda, Dipti Gupta and Hong-Cheu Lin*. "Highly Stretchable Supramolecular Conductive Self-Healable Gels for Injectable Adhesive and Flexible Sensor Applications". **J. Mater. Chem. A** 2020, 8 (38), 19954–19964.
2. **Amir Khan,** Sreekanth Ginnaram, Chia-Hua Wu, Hong-Wei Lu, Yi-Fang Pu, Judy I. Wu, Dipti Gupta, Ying-Chih Lai*, Hong-Cheu Lin*. "Fully Self-Healable, Highly Stretchable, and Anti-Freezing Supramolecular Gels for Energy-Harvesting Triboelectric Nanogenerator and Self-Powered Wearable Electronics". **Nano Energy** 2021, 90, 106525.
3. **Amir Khan,** Shahzad Ahmed, Bo-Yao Sun, Yi-Chen Chen, Wei-Tsung Chuang, Yang-Hsiang Chan, Dipti Gupta, Pu-Wei Wu, Hong-Cheu Lin*. "Self-healable and anti-freezing ion conducting hydrogel-based artificial bioelectronic tongue sensing toward astringent and bitter tastes". **Biosens. Bioelectron.** 2021 (just accepted).

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