Design and Development of Soft Gel based Sensor

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Abstract. Gel based sensor for personal health monitoring and human–machine interaction has attracted enormous interests. We design and develop a novel conductive polyacrylic acid/polyaniline (PAA/PANI) hydrogel with ultra-stretchable and self-healing feature. The PAA and PANI chains in hydrogel were entangled and the doping interaction was acted as sacrificial bonds to offer PAA/PANI hydrogel with ultra-stretchability (2830%), high breaking strength (120 kPa) and rapid self-healing properties. The prepared gel based sensor can be utilized to monitor various human movements precisely, and display promising a broad application prospect in wearable devices.

Introduction:

Hydrogels have emerged as one of most promising candidates for biological applications because of their similarities to natural tissues, excellent flexibility and self-healing properties [1-4]. Among the various functional hydrogels, press/strain-responsive hydrogels can mimic the functions of human skin with mechanical and sensory properties by combining the electrical/ion conductivity with the soft nature of hydrogels, and convert the mechanical deformation to detective electrical signals without affecting human activities rapidly and efficiently, have drawn great attention in the field of wearable sensors recent years [5,6].

Here, we creatively fabricated an ultra-stretchable PAA/PANI hydrogel by entangled PANI and PAA together. The PANI was firstly doped by acrylic acid (AA) monomer, which could not only facilitate PANI to dissolve in water but also enhance the conductivity of PANI. Then, the formed PAA/PANI hydrogels with entanglement network were obtained by polymerizing PAA. On one hand, the uniformly dispersed PANI provide doping effect with PAA, the doping effect is acted as sacrificial bonds to offer PAA/PANI hydrogel with superb mechanical performances, leading to outstanding mechanical properties including ultra-stretchability (2830%), high breaking strength (120 KPa) and rapid self-healable. On the other hand, the uniform and continuous conductive network is beneficial for sensing ability. Consequently, CHs with ultra-stretchability, excellent conductivity, and high sensitivity were achieved. The synthesis of PAA/PANI hydrogel. is shown in figure 1.

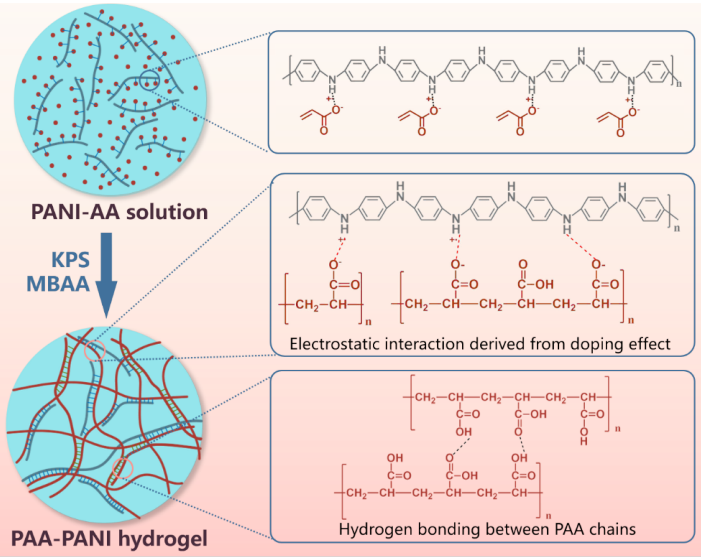

Fig. 1. Schematic image of synthesis process of the PAA/PANI hydrogel.

Mechanical behaviour: The tensile strength, elongation at break and toughness of all the four PAA/PANI hydrogels are higher than that of pure PAA hydrogel, attributing to the strong electrostatic interactions that are derived from the doping effect between PAA and PANI. Furthermore, PAA composited with 2 mg PANI (PAA/PANI-2) exhibited the highest mechanical properties with a large ultimate strain of 2830% at a strength of about 120 kPa, while PAA/PANI-3 possessed highest toughness of 1.542 MJ m^{-3}. As the content of PANI increased, the tensile strength, elongation and fracture toughness of PAA/PANI hydrogels increased continuously. However, the mechanical properties of PAA/PANI hydrogel were decreased sharply when added more than 3 mg PANI.

Electronic behavior and the sensitivity. For the PAA/PANI-3 hydrogel sensor, the GF value was calculated to be 3.21 at low strain from 0 to 200%, and increased to 6.11 at higher strain from 200% to 800%, then up to 12.63 under highest strain range of 800%-2000%, comparable to that of recently reported hydrogel sensors [7, 8]. The hydrogel sensor could recognize large strain range from the minimal strain of 1% to large strain of 400%. The electrical signals presented a frequency-dependency when the hydrogel sensor was subjected to

different stretching frequencies (0.04–0.32 Hz). The conductivity (σ) of PAA/PANI-3 was determined to be σ=1.18 mS cm^{-1}, which is one order of magnitude higher than that of PAA hydrogel (0.137 mS cm^{-1}), leading to higher electron transfer speed. The PAA/PANI-3 and PAA hydrogels were loaded with 1% strain to evaluate their response time. It can be found the response time of the PAA/PANI-3 hydrogel was calculated to be 222 ms, faster than that of PAA hydrogel (253 ms).

Sensors for the detection of human motion. The PAA/PANI-3 hydrogel was applied to see-through human body signal detection. The sensor was directly attached onto the volunteer's skin to monitor both large and subtle movements, $\Delta R/R_0$ of the hydrogel during body movement were recorded. We firstly used the hydrogel sensor to feel the slight physiological changes, When the hydrogel sensor was attached to human's cheek, the volunteer open and close his mouth were detected and indicated in Figure 2a. The zonation of different words could be recognized by the hydrogel sensor when touched the sensor to human's throat, such as "nihao" and "xjtu" (Figure 2b). The sensor showed a reproducible resistance change with specific peak waveforms for

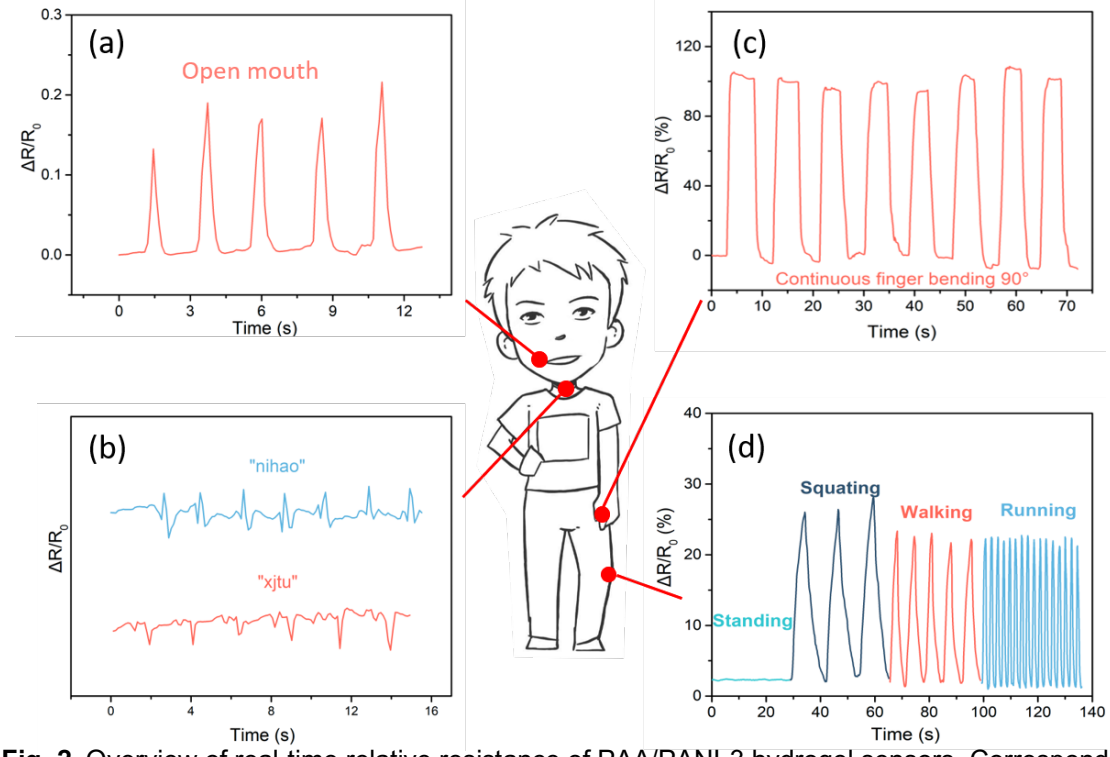

Fig. 2. Overview of real-time relative resistance of PAA/PANI-3 hydrogel sensors. Corresponding signals from (a) cheek, (b) throat vocalization, (c) finger and (d) knee joint.

different words. Besides the small transform that detect human's physiological state, Figure 2c exhibits the strain sensors attached on the second joint of finger with cyclic bending. The recyclability in the bending measurement demonstrates that the as-prepared PAA/PANI-3 hydrogel sensor can be controlled to a designed state precisely. As shown in Figure 2d, the sensor was attached to the knee to perceive the motion of the human body such as standing, squatting, walking and running with specific output signals. All these consequences verified that the obtained PAA/PANI hydrogel sensors possess reliable and greatly sensitive for practical use in wearable devices.

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