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# A self-healing hydrogel with pressure sensitive photoluminescence for remote force measurement and healing assessment


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## Introduction

Self-healing dimming materials exhibit interesting colour changes when exposed to external stimuli such as light, temperature, pH and force. These interesting properties are important for the advancement of new colour-developing and fluorescent colour-changing materials for applications in sensors, structural health monitoring systems, optical force measuring devices, flexible devices, tissue engineering and regenerative medicine. Hydrogels are hydrophilic polymers which swell in water but are insoluble in water. These materials have a high water content, good flexibility, and a strong ability to penetrate into small molecules. Besides, the unique network structure provides hydrogels with excellent biocompatibility and self-healing abilities. However, in practical applications, hydrogels exhibit relatively long healing times, stimuli dependence, poor healing performance in humid environments, and an unstable optical performance. It would be of great interest to prepare the hydrogels with ultra-fast self-healing properties (no external stimuli, multiple environmental adaptations) and a stable optical response.

## Methods and results

We propose a multi-network structure of a fluorescence-responsive self-healing hydrogel (hydrogen bonds). 1. Main skeleton structure: hydrogen bonds between chitosan–agarose, chitosan–PVA, and agarose–PVA; 2. Dynamic healing structure: the hydrogen bonds among PVA–borax–PVA and PVA–glycerol–; 3. Fluorescence function structure: the static hydrogen bond network between PVA and the quantum dots (water-soluble/fat-soluble carbon quantum dots, MXene quantum dots)

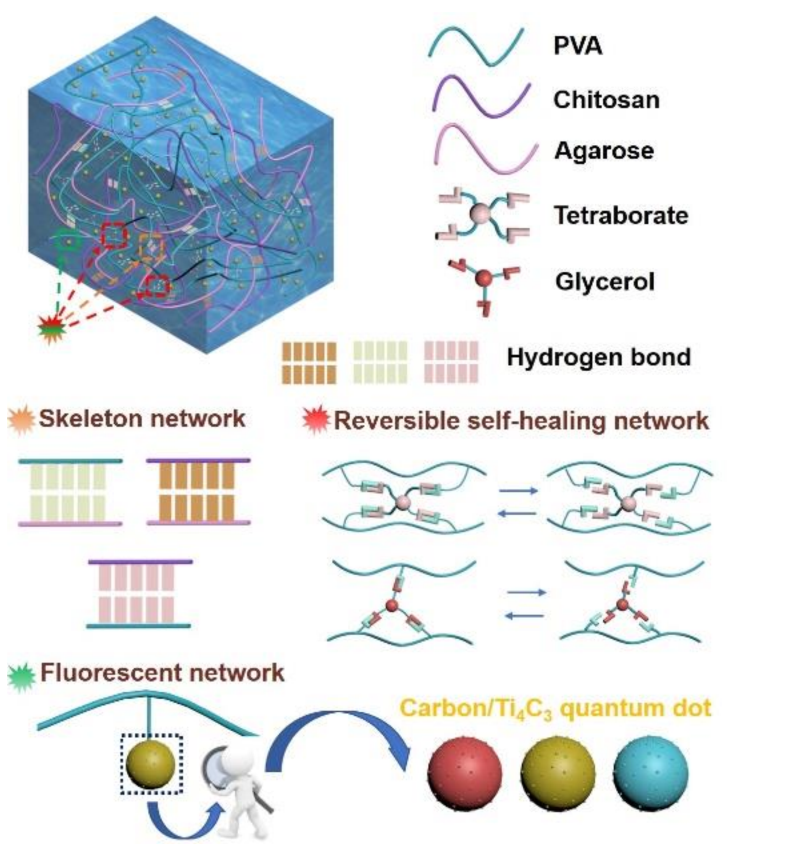



Fig.1. Schematic of the internal structure and bonds of the photoluminescent self-repairing hydrogel

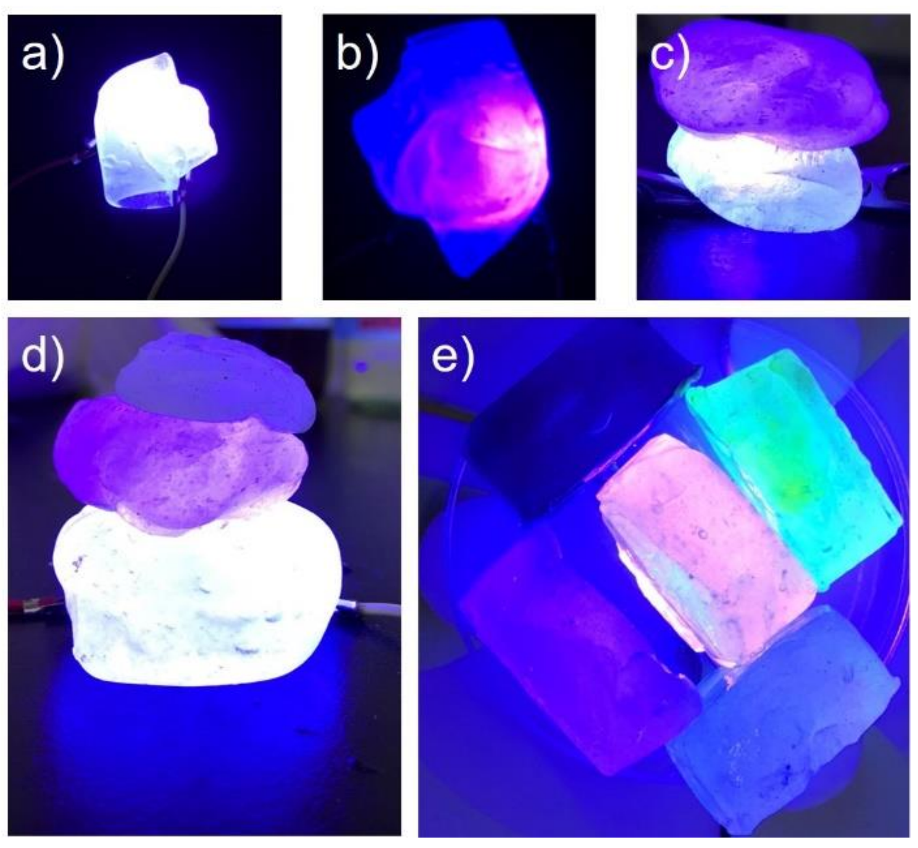


Fig.2. The color of hydrogel doped with various colors of quantum dots under the purple LED chip.

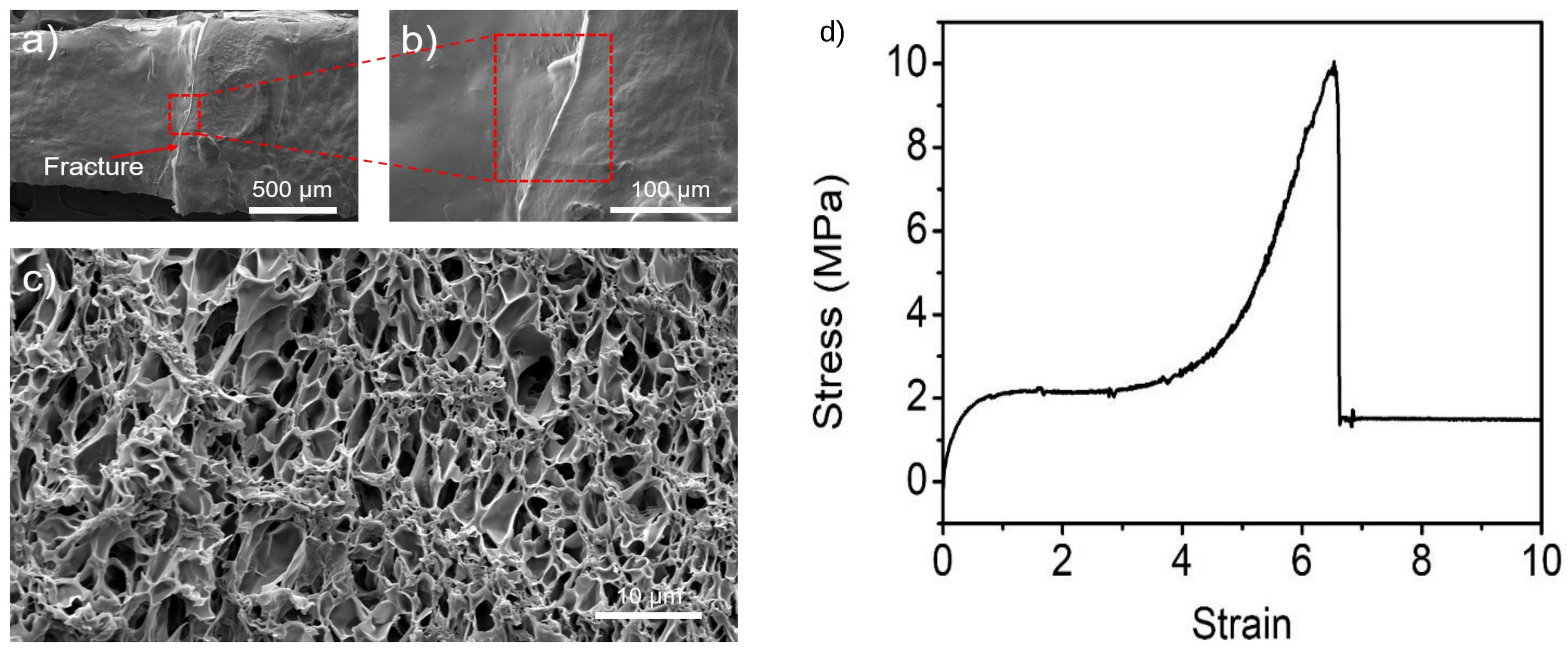



Fig.3. a,b) SEM images of surface self-healing; c) SEM image of the internal structure of the self-healing surface; d) Composite surface tensile strength up to 10.21 MPa.

## Self-healing performance

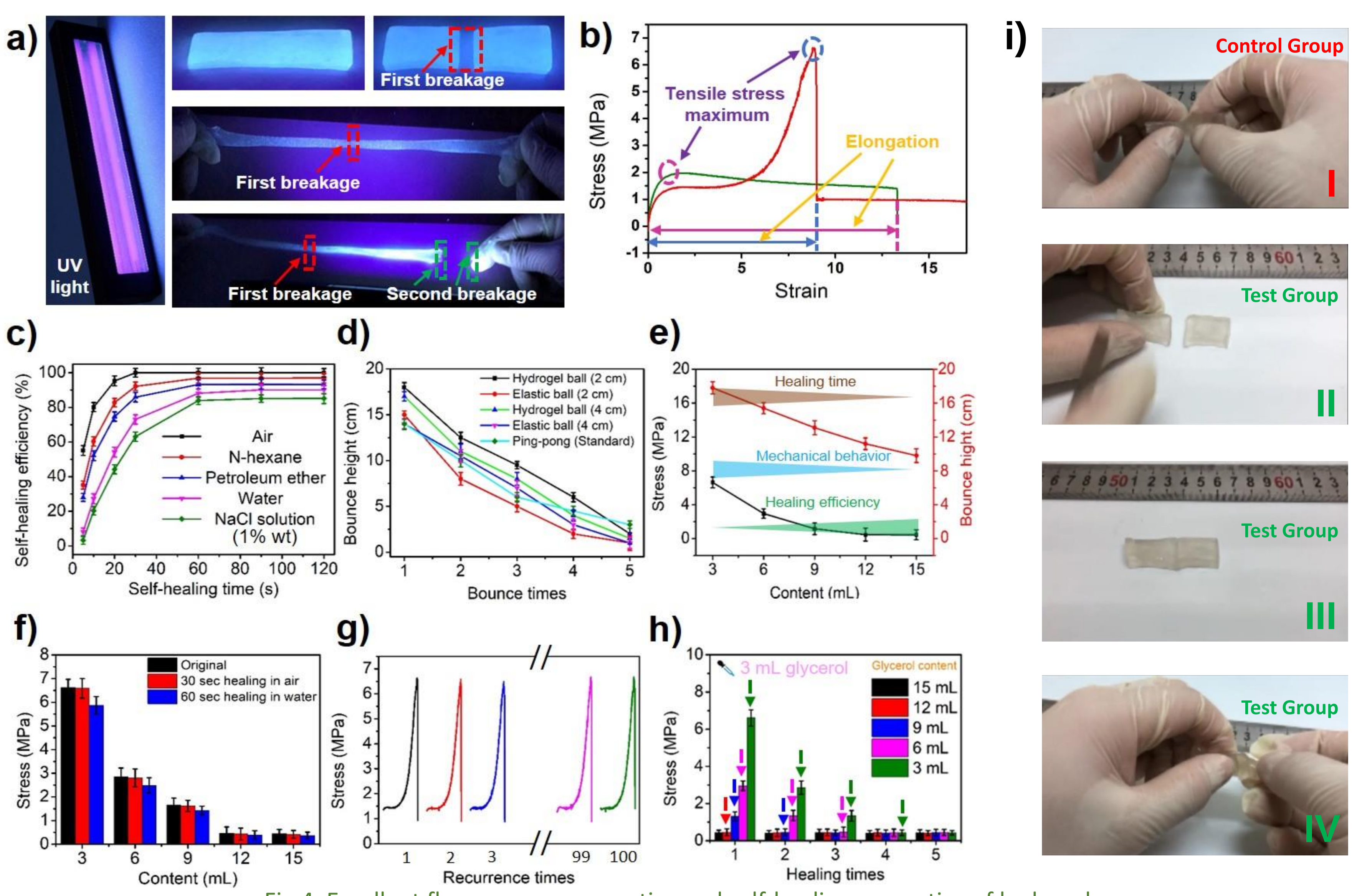



Fig.4. Excellent fluorescence properties and self-healing properties of hydrogel

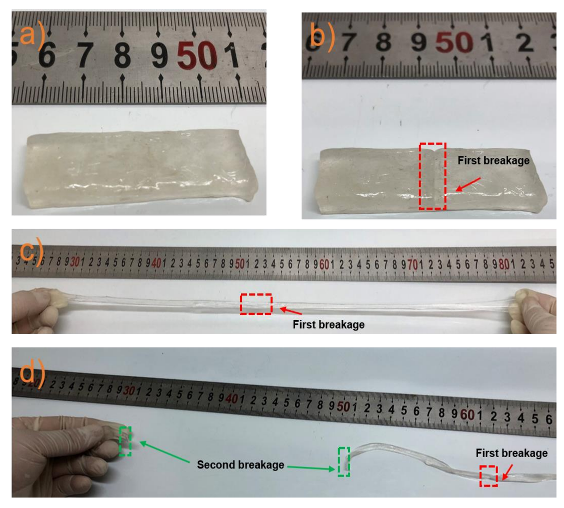



Fig.5. Self-healing photos of hydrogel in air

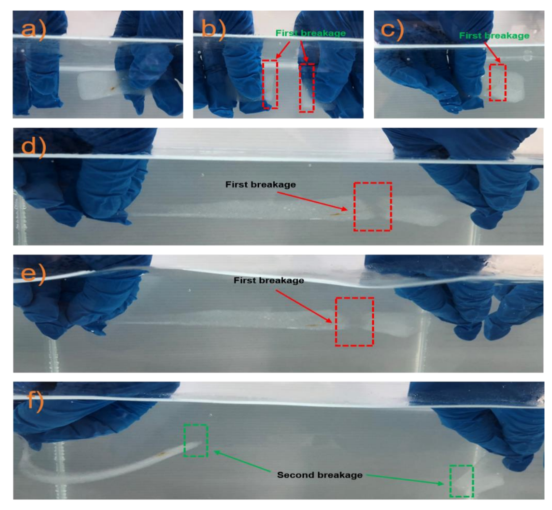


Fig.6. Hydrogel self-healing in water

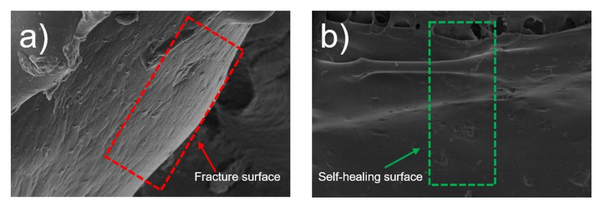



Fig.7. SEM photo of damaged self-healing hydrogel

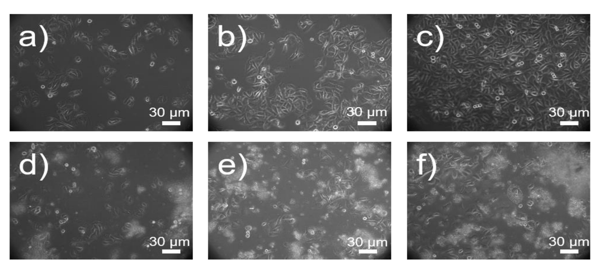


Fig.8. Image of prostate cancer cells on hydrogel

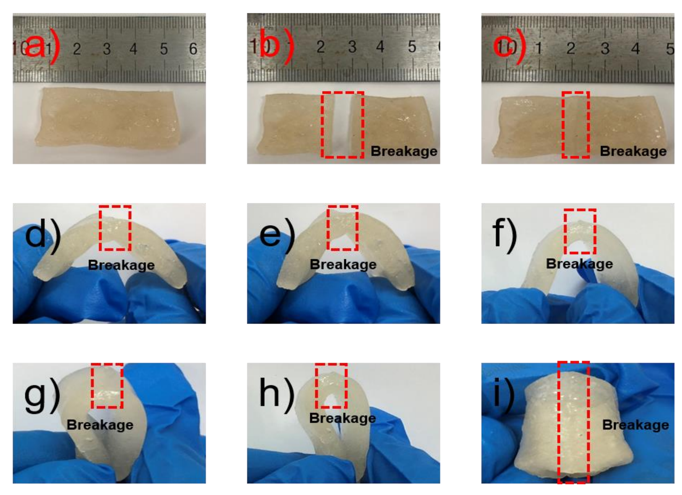



Fig. 9. a) Photo of the initial hydrogel. b) Hydrogel after being cut. c) Hydrogel after self-healing. d-i) Different angles displaying the self-healed hydrogel.

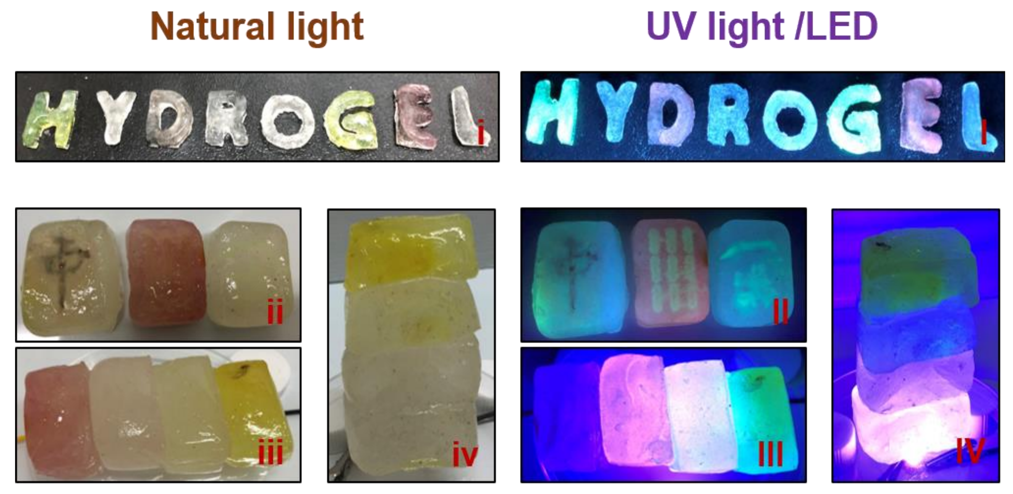



Fig. 10. The colour of hydrogel doped with quantum dots of various colours under natural or UV lights (purple LED chip).

## Applications and principles

As the fluorescence excitation intensity of the hydrogel shows a good correspondence with the forces exerted on the hydrogel, the forces and the self-healing efficiency could be determined by measuring the intensity of the excitation peak. The stress states of the hydrogel in different liquids could be remotely monitored, eliminating the effect of surface contacts.

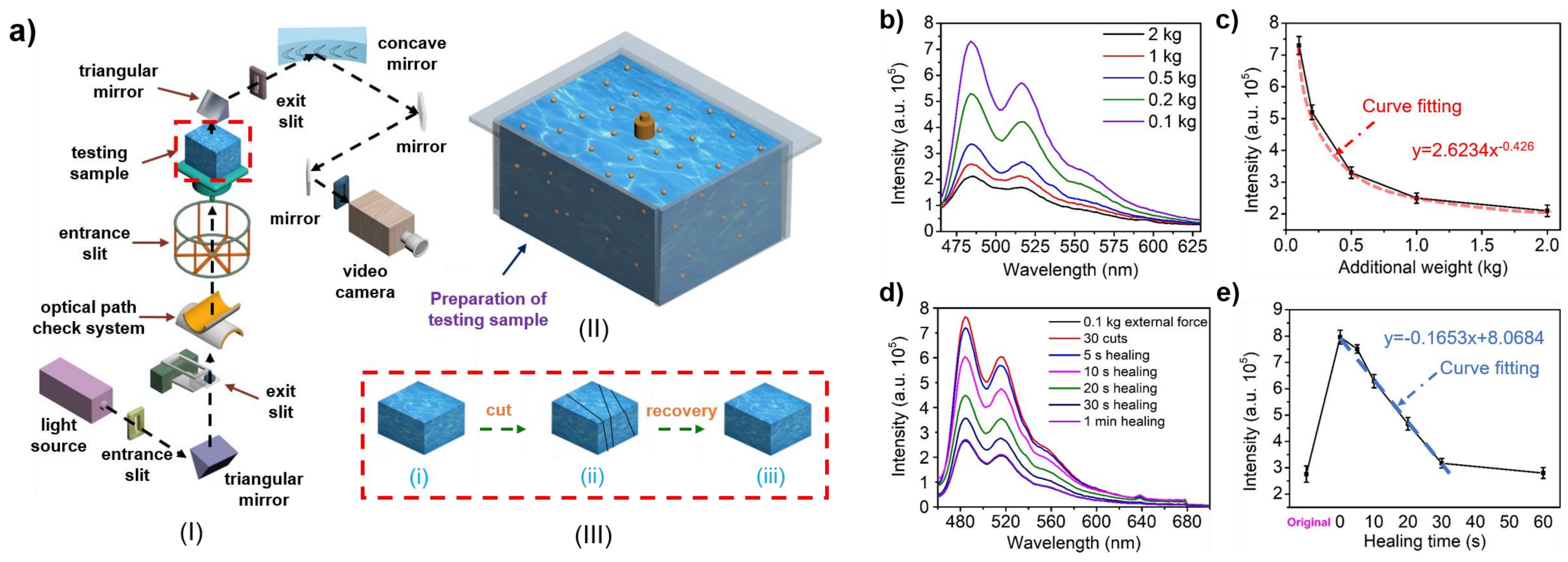
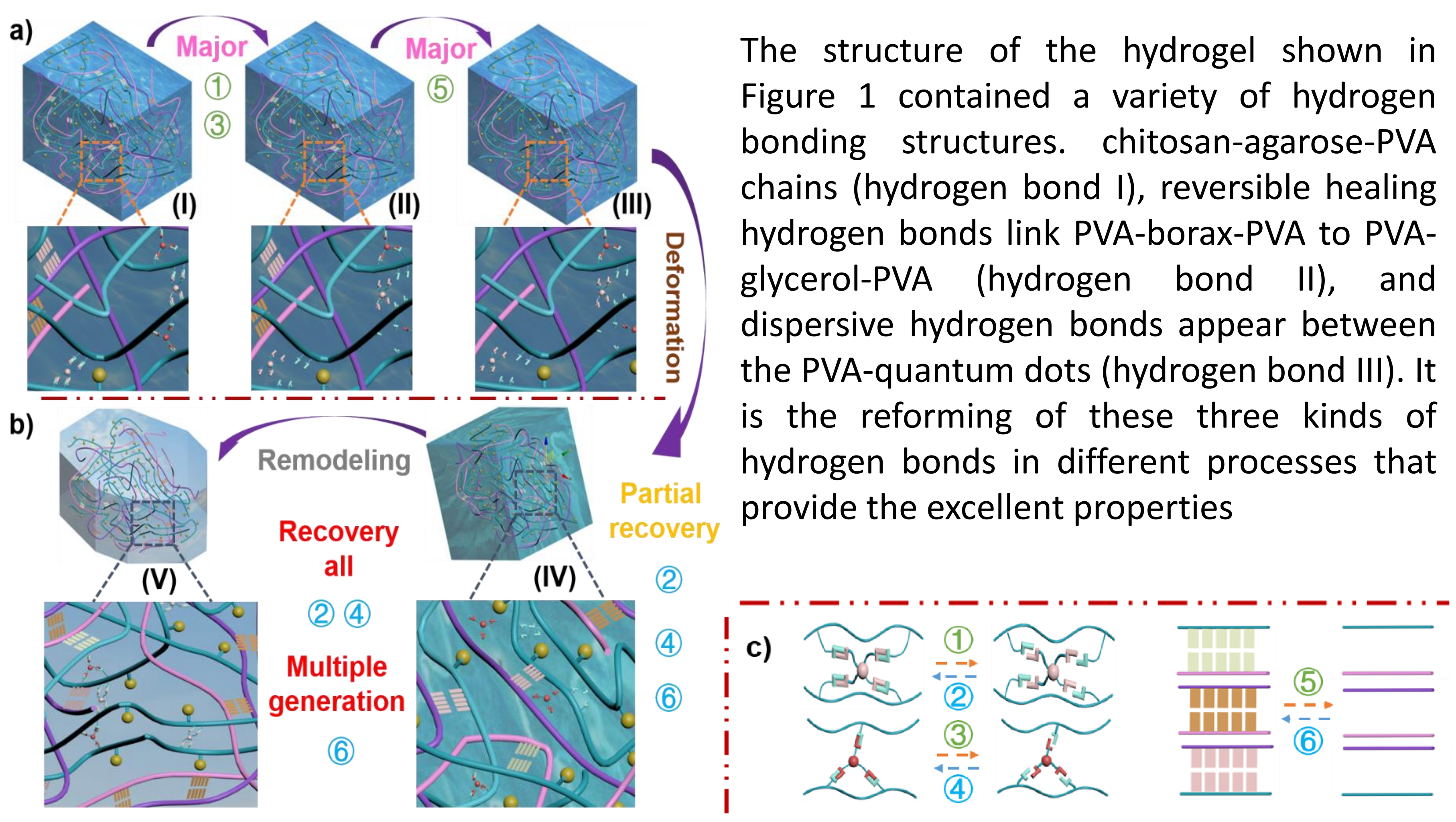



Fig.11. (a) Mechanism of a hydrogel fluorescence emission intensity test. (b) Relationship between the fluorescence intensity of the hydrogel (doped with carbon quantum dots) and its state (original, cut, healed). (c) A fitted curve between the fluorescence intensity of the hydrogel (doped with carbon quantum dots) and its state (original, cut, healed). (d) The relationship between the fluorescence intensity of the hydrogel (doped with carbon quantum dots) and the external force to which the hydrogel was subjected. (e) A fitted curve between the fluorescence intensity of the hydrogel (doped with carbon quantum dots) and the external force it was subjected to.




The structure of the hydrogel shown in Figure 1 contained a variety of hydrogen bonding structures. chitosan-agarose-PVA chains (hydrogen bond I), reversible healing hydrogen bonds link PVA-borax-PVA to PVA-glycerol-PVA (hydrogen bond II), and dispersive hydrogen bonds appear between the PVA-quantum dots (hydrogen bond III). It is the reforming of these three kinds of hydrogen bonds in different processes that provide the excellent properties

Fig.11. Schematic of the number of bonds and state changes in the hydrogel when subjected to external forces. a) Bonds breaking stage in the hydrogel. b) Deformation and reconstruction stage of the hydrogel. c) Bonds broken and formation reaction in the hydrogel.

## Conclusions

1. Self-healing hydrogels have excellent self-repair capabilities. Self-healing can be achieved in different media (air, water, oil, salt solution), acidic or alkaline solutions (pH: 1-14).

2. The addition of carbon and Mxene dots provide fluorescent properties. The hydrogel can reach full spectral coverage and can be used in LED devices.

3. For the first time, non-contact stress detection (accuracy greater than 94%) and surface self-healing monitoring (accuracy greater than 99%) were achieved.

## Reference


Li, Ming, et al. “A self-healing hydrogel with pressure sensitive photoluminescence for remote force measurement and healing assessment.” Materials Horizons 6.4 (2019): 703-710.