

SUPPORTING INFORMATION

White-light-emitting thin film based on blue Metal-organic frameworks and red fluorescent proteins

Xiaobin Wang, Zhuoyi Li, Wen Ying, Danke Chen, Peipei Li, Zheng Deng, Xinsheng Peng*

Abstract: Fluorescent proteins (FPs) with good photostability and outstanding photoluminescence features are very promising luminous materials for white-light-emitting diodes (WLEDs) fabrication. However, their requirement for an aqueous environment and poor thermal stability have strongly restricted their wide applications in lighting devices. In this paper, we present a facile strategy to encapsulate R-Phycoerythrin (R-PE) fluorescent proteins into a blue metal organic framework (MOF) HSB-W1 (HSB = hydrogenated schiff base) thin film through a facile solid-confinement conversion process. As a result, R-PE proteins embedded into HSB-W1 crystals are denatured but exhibit dual color fluorescence emissions including green (518 nm) and red (600, 647 nm) lights, while the original single orange light (578 nm) is significantly suppressed. After careful adjustment of R-PE content, the resulting R-PE@HSB-W1 thin film emits high-quality white light with nearly ideal Commission Internationale de l'Éclairage (CIE) coordinates of (0.33, 0.34), high color rendering index (CRI) value of approximately 85 and moderate correlated color temperature (CCT) value of 5740 K. Such strategy can be widely utilized for other fluorescence molecules and luminescent MOFs to design white-light-emitting materials.

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1. Additional SEM images and PL results:

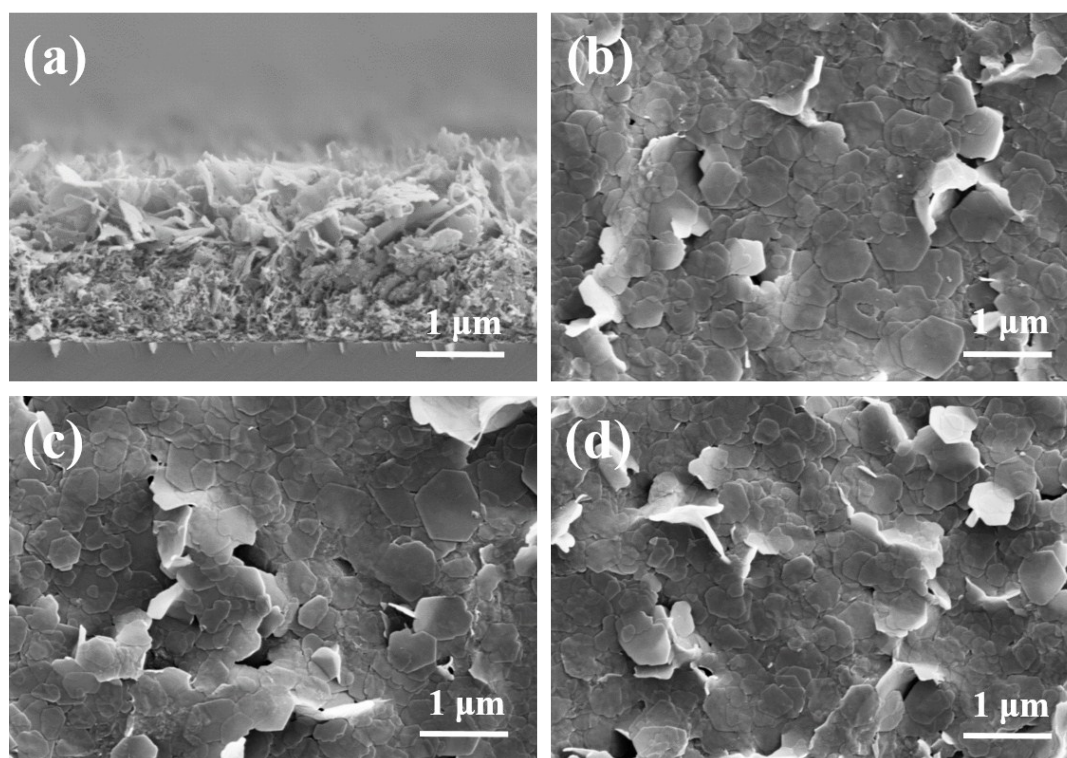


Fig. S1 (a) Cross-section SEM image of HSB-W1 (S-1) thin film. Surface SEM images of R-PE@HSB-W1 thin films (b) S-3, (c) S-4 and (d) S-5.

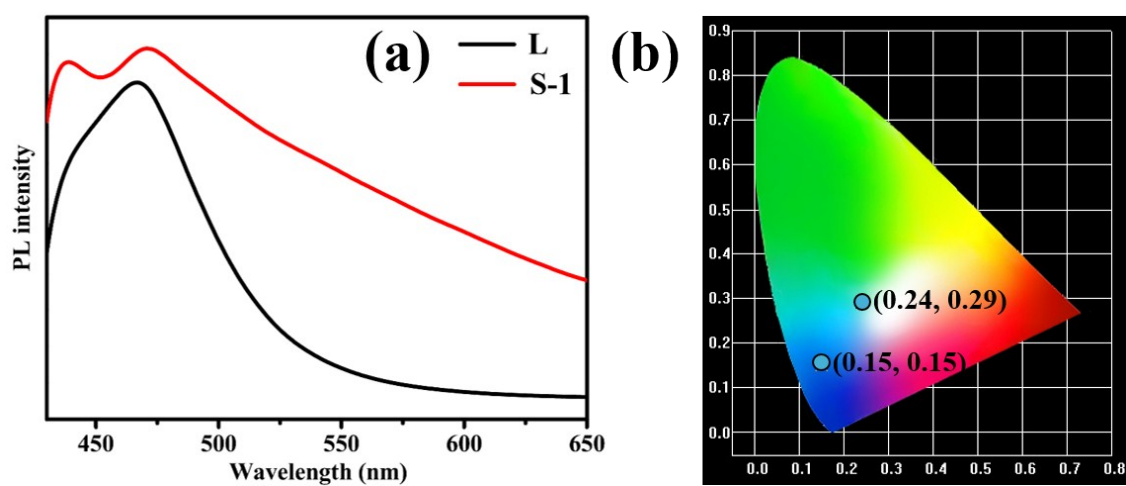


Fig. S2 (a) PL spectra of the hydrogenated Schiff base L and HSB-W1 thin film; (b) Emission colors in the CIE 1931 chromaticity diagram of the hydrogenated Schiff base L and HSB-W1 thin film excited at 405 nm.

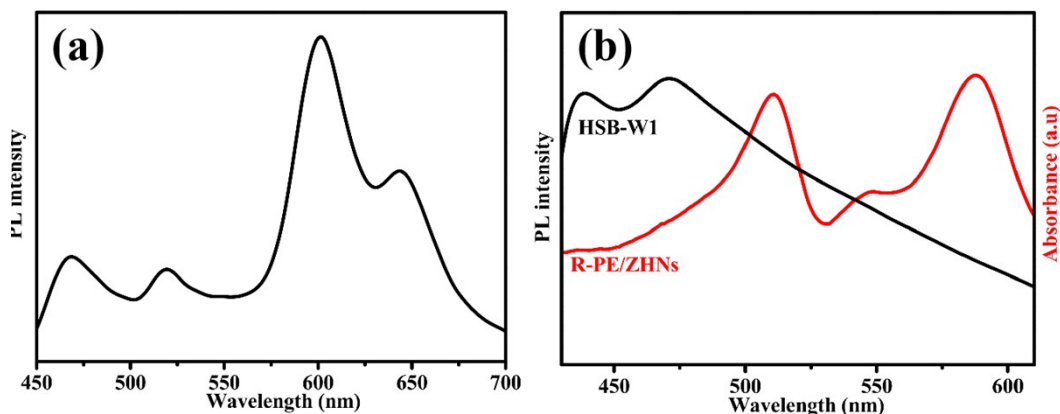


Fig. S3 (a) PL spectrum of R-PE/ZHNs thin film excited at 405 nm; (b) PL spectrum of HSB-W1 excited at 405 nm and UV-Vis absorption spectrum of R-PE/ZHNs.

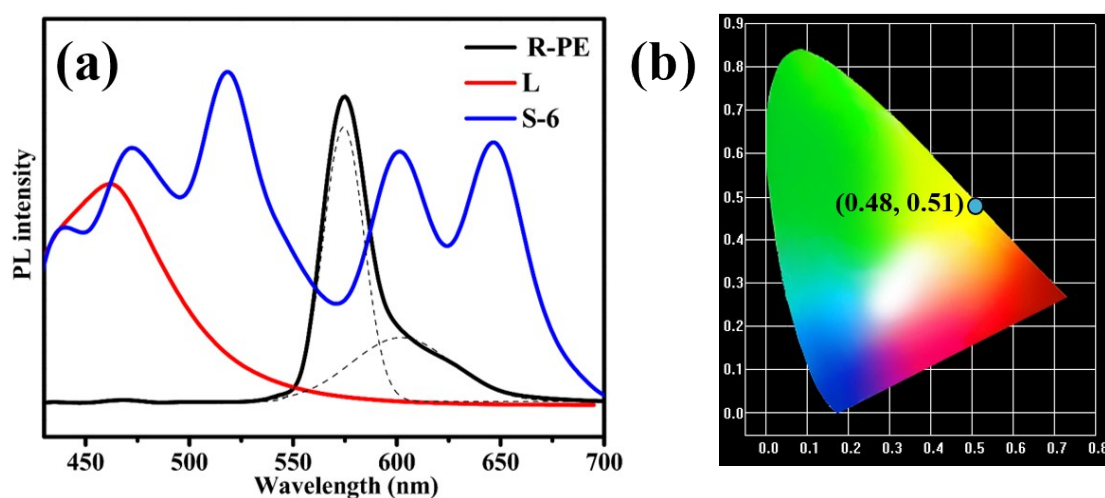


Fig. S4 (a) PL spectra of the R-PE@HSB-W1 thin film (S-6), R-PE and the hydrogenated Schiff base L aqueous solution excited at 405 nm; (b) Emission colors in the CIE 1931 chromaticity diagram of the R-PE aqueous solution excited at 405 nm.

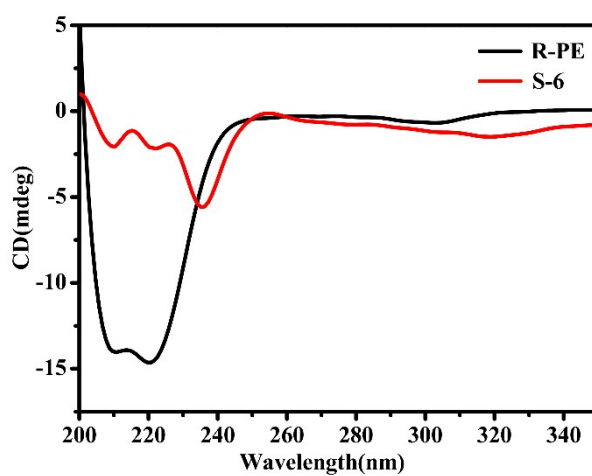


Fig. S5 CD spectra in the far UV of R-PE solution and R-PE@HSB-W1 (S-6).

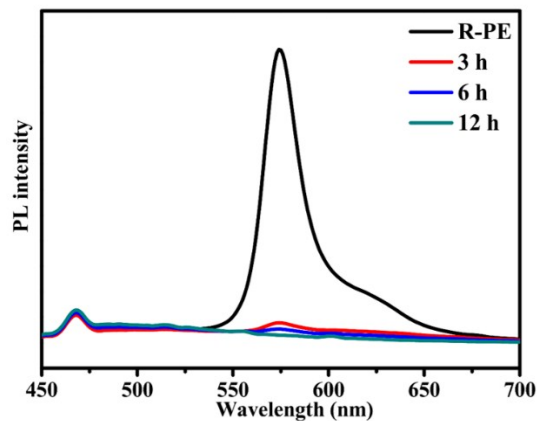


Fig. S6 PL stability of the R-PE aqueous solution treated at 80 °C, excited at 405 nm.

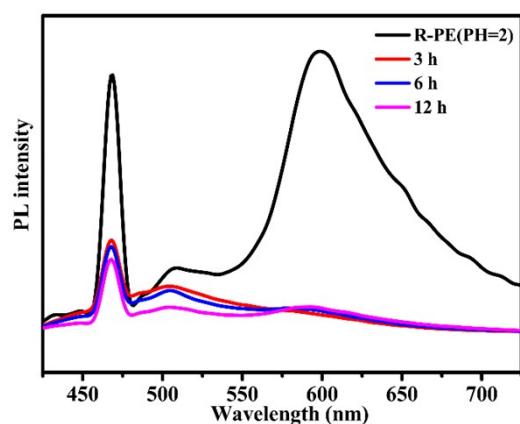


Fig. S7 PL stability of the pre-denatured R-PE aqueous solution at 80 °C for different time, excited at 405 nm.

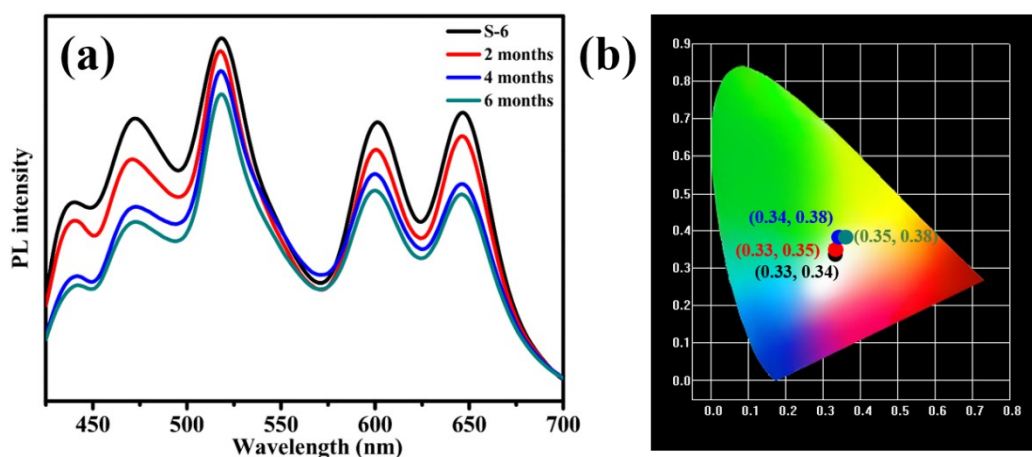


Fig. S8 (a) PL spectra of the R-PE@HSB-W1 thin films (S-6) stored under atmospheric conditions up to 6 months, excited at 405 nm; (b) Emission colors in the CIE 1931 chromaticity diagram of the corresponding R-PE@HSB-W1 thin films excited at 405 nm.

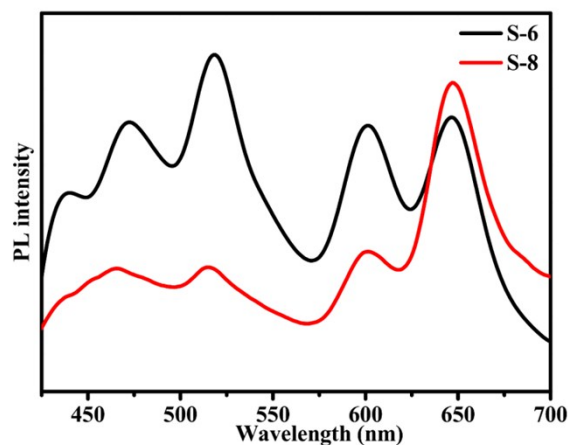


Fig. S9 PL spectra of the R-PE@HSB-W1 thin film (S-6) and pre-denatured R-PE (pre-denatured at pH 2) @HSB-W1 (S-8) thin film, excited at 405 nm.

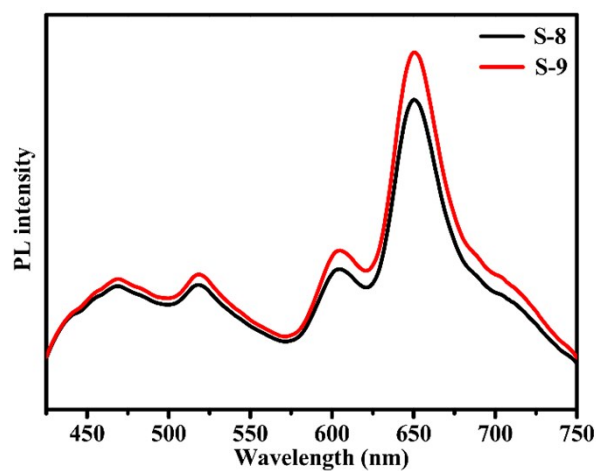


Fig. S10 PL spectra of the R-PE (pre-denatured) @HSB-W1 thin film (S-8) stored under atmospheric conditions for 1 month, excited at 405 nm.

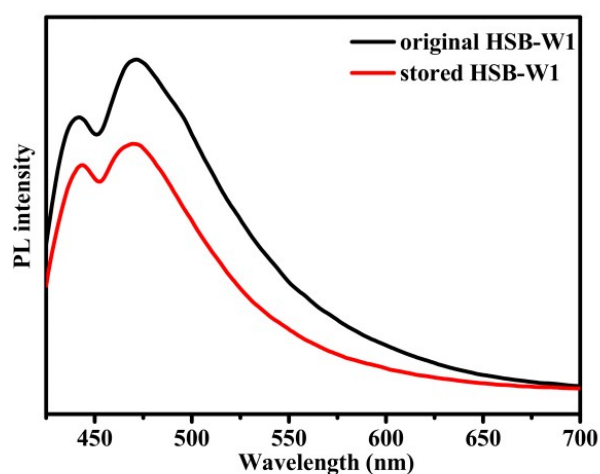


Fig. S11 PL spectrum of original HSB-W1 and stored HSB-W1, excited at 405 nm.

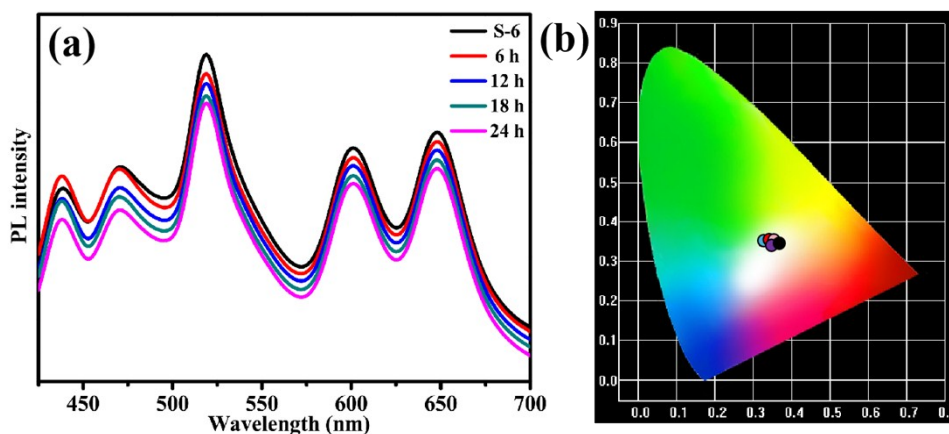


Fig. S12 (a) PL spectra of the R-PE@HSB-W1 thin films (S-6) after operating up to 24 hours, excited at 405 nm; (b) Emission colors in the CIE 1931 chromaticity diagram of the corresponding R-PE@HSB-W1 thin films excited at 405 nm.

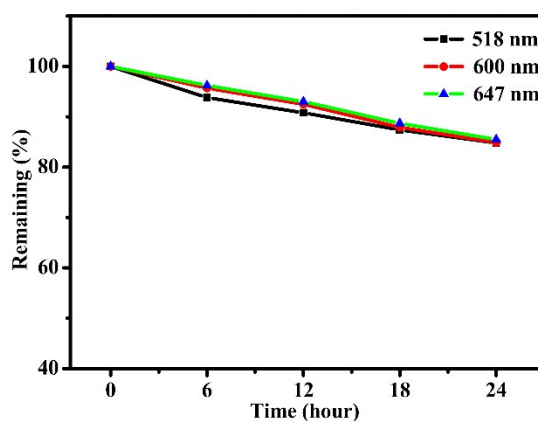


Fig. S13 The time dependent PL intensity of R-PE@HSB-W1 continuously illuminated by 405 nm UV-violet LED chip operating at 14 mA/cm² up to 24 hours.

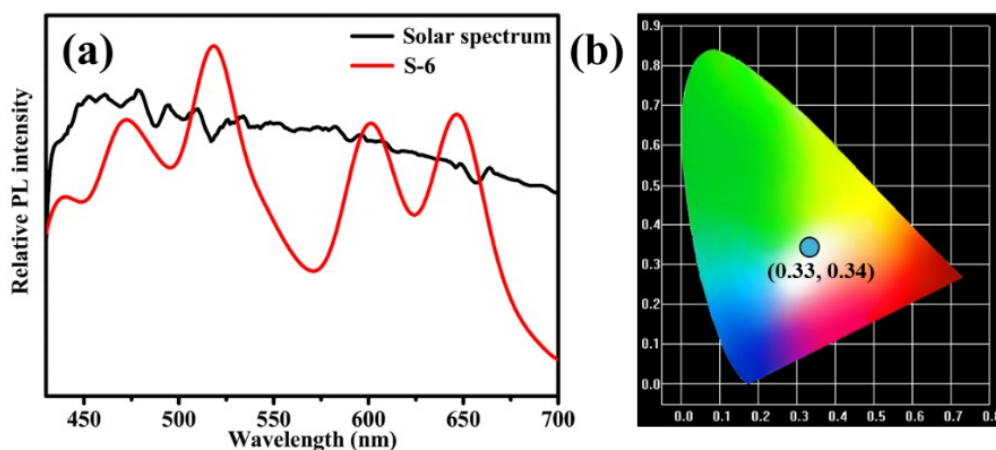


Fig. S14 (a) PL spectra of sunlight at 5000 K and the R-PE@HSB-W1 thin film (S-6) excited at 405 nm; (b) Emission colors in the CIE 1931 chromaticity diagram of the sunlight at 5000 K.

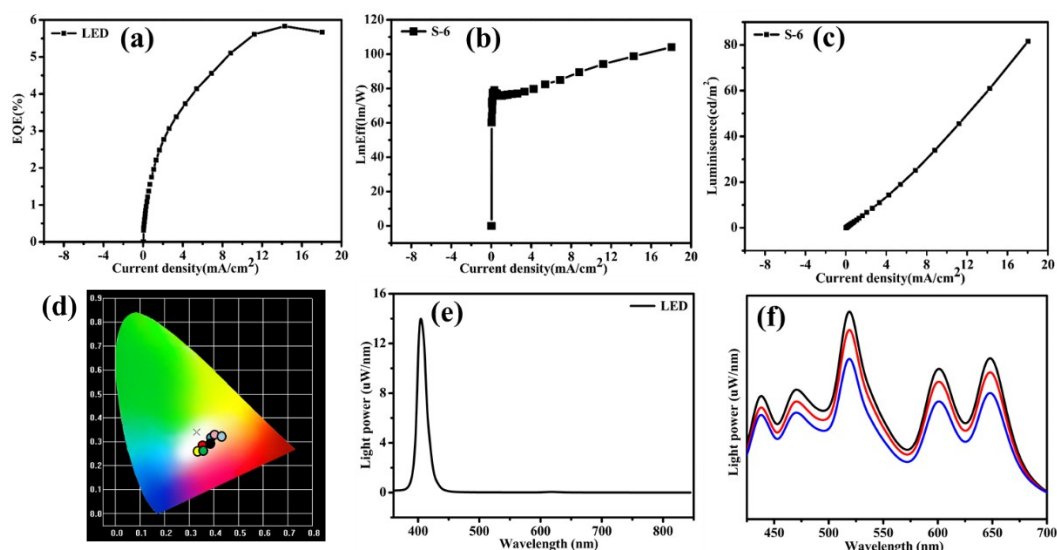


Fig. S15 EQE of UV-violet LED chip upon increasing the applied current; (b) luminous efficiency of R-PE@HSB-W1 (S-6) upon increasing the applied current; (c) luminous intensity of R-PE@HSB-W1 (S-6) upon increasing the applied current; (d) emission colors in the CIE 1931 chromaticity diagram of R-PE@HSB-W1 (S-6) upon increasing the applied current, excited at 405 nm; (e) the EL spectrum of the UV-violet LED chip; (f) the EL spectra of R-PE@HSB-W1 (S-6) under different applied currents (8 mA/cm² blue, 12 mA/cm² red, 14 mA/cm² black).

2. Additional tables:

Table S1. R-PE content and CIE coordinates of all the membranes we prepared.

Sample	ZHNs /mL	R-PE solution /mL	R-PE Content (wt%)	CIE(x)	CIE(y)
S-1	10	0	-	0.24	0.29
S-2	10	0.5	0.53	0.30	0.36
S-3	10	1	1.1	0.30	0.35
S-4	10	1.5	1.6	0.31	0.35
S-5	10	1.8	1.9	0.33	0.35
S-6	10	2	2.1	0.33	0.34
S-7	10	2.2	2.4	0.34	0.36
S-8	10	1.5 (denatured)	1.6	0.37	0.33

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Table S2. PLQY of R-PE aqueous dispersion, HSB-W1 and R-PE@HSB-W1 membranes.

Sample	PLQY (%)
R-PE aqueous dispersion	13
HSB-W1 (S-1)	30
R-PE@HSB-W1 (S-6)	60