Electronic Supplementary Material (ESI) for Materials Advances.

Support Information

A novel PVDF hybrid membrane with excellent active-passive integrated antifouling and antibacterial properties based on PDA guiding effect

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Morphology and structure of the PVDF/PDA-AgNPs hybrid membranes

Figure S1. SEM morphologies of M1 and the PVDF/PDA-AgNPs hybrid membranes.

Morphology and structure of the PVDF/PDA-AgNPs-Cys hybrid membranes

Figure S2. SEM morphologies of the PVDF/PDA-AgNPs-Cys hybrid membranes.

SEM-EDS mapping analysis of M3-4

Figure S3. Element distributions of the surface and cross-section of M3-4.

The CFU counting method to assess the antibacterial properties

Figure S4. The normalized CFU data of the various membranes.

Morphology and structure of the PVDF/PDA-AgNPs hybrid membranes

The surface and cross-section morphology of the membranes were observed by SEM to confirm the immobilization of AgNPs and Cysteine flowers on the membranes. In our previous work, it had been discussed that there were a great number of PDA microspheres immobilized on the surfaces and cross-section after PDA modification, especially on the cross-section. The images were showed in Figure S1A, E and I. In this paper, the prepared PVDF/PDA hybrid membrane was directly incubated in silver nitrate aqueous solution at first. As can be seen from Figure S1B-D, F-H and J-L, bright AgNPs with about 30 nm in average diameter were clearly observed on the surfaces of PDA microspheres, as well as on the surfaces and cross-section of membranes. With the increasing concentrations of silver nitrate solution from 5 to 40 mM, the density and average diameter of the immobilized AgNPs were gradually increased. Thus, the concentration of silver nitrate solution was an important factor that could control the density and diameter of the immobilized AgNPs. It was believed that the concentration of 40 mM was the optimum condition for the further modification, and the preparation of the PVDF/PDA-AgNPs-Cys hybrid membranes was on the basis of M2-40. Besides, the membrane pores of all the PVDF/PDA-AgNPs hybrid membranes could be observed apparently from the SEM images, indicating that the deposition of AgNPs did not cause the blockage of membrane pores.

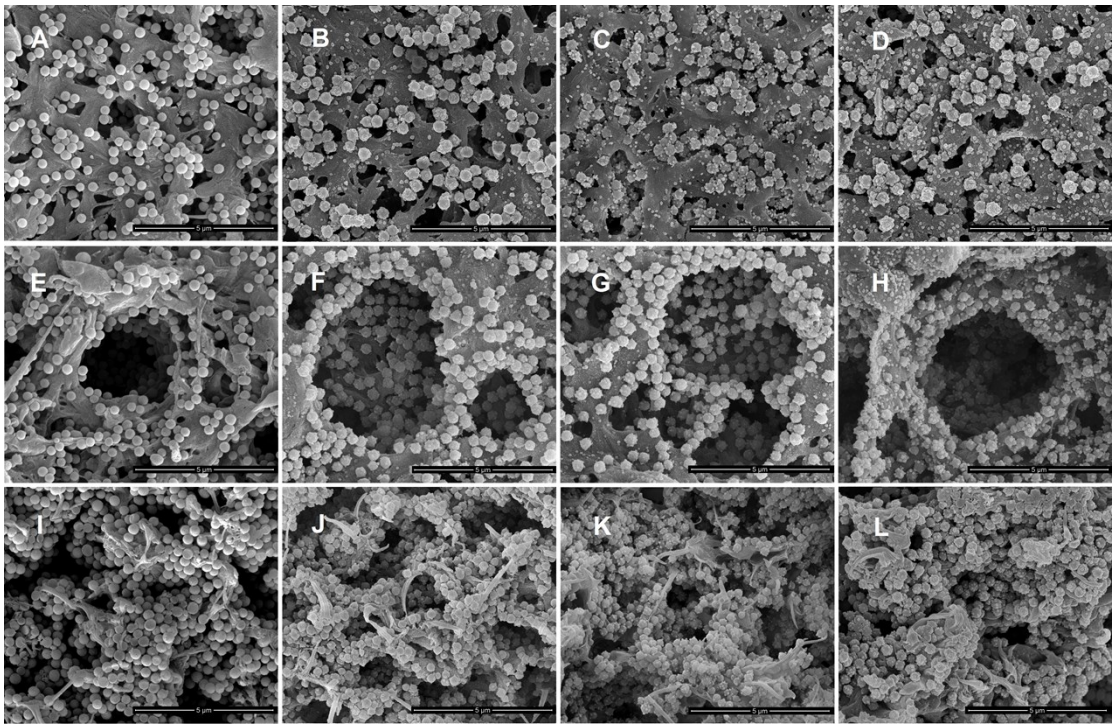

Figure S1. Morphologies and structures of M1 and the PVDF/PDA-AgNPs hybrid membranes: SEM images of the upper surface (A, B, C, D), lower surface (E, F, G, H), and cross-section (I, J, K, L) of the various membranes, M1 (A, E, I), M2-5 (B, F, J), M2-20 (C, G, K), and M2-40 (D, H, L).

Morphology and structure of the PVDF/PDA-AgNPs-Cys hybrid membranes

The prepared PVDF/PDA-AgNPs hybrid membranes were further functionalized with L-cysteine via Michael addition reaction and the SEM results were showed in Figure S2. The upper and lower surfaces of M3-1 in Figure S2A and E showed that the plate-like L-cysteine was dispersed and toppled on the surfaces, causing a great deal of PDA microspheres and AgNPs were covered. Figure S2B-D and F-H exhibited that as the concentration of L-cysteine increased from 1 mg mL^{-1} to 4 mg mL^{-1}, the plate-like L-cysteine was gradually gathered and then superimposed randomly on the surfaces. When the concentration reached to 3 mg mL^{-1}, the L-cysteine clusters presented the shape of flower and the stereoscopic forms were also enhanced. It was obviously that the cysteine flowers on M3-4 surfaces displayed the largest volume and the best stereoscopic form without serious coverage of PDA microspheres and AgNPs. This enabled the performances of PDA, AgNPs, and L-cysteine to be fully reflected.

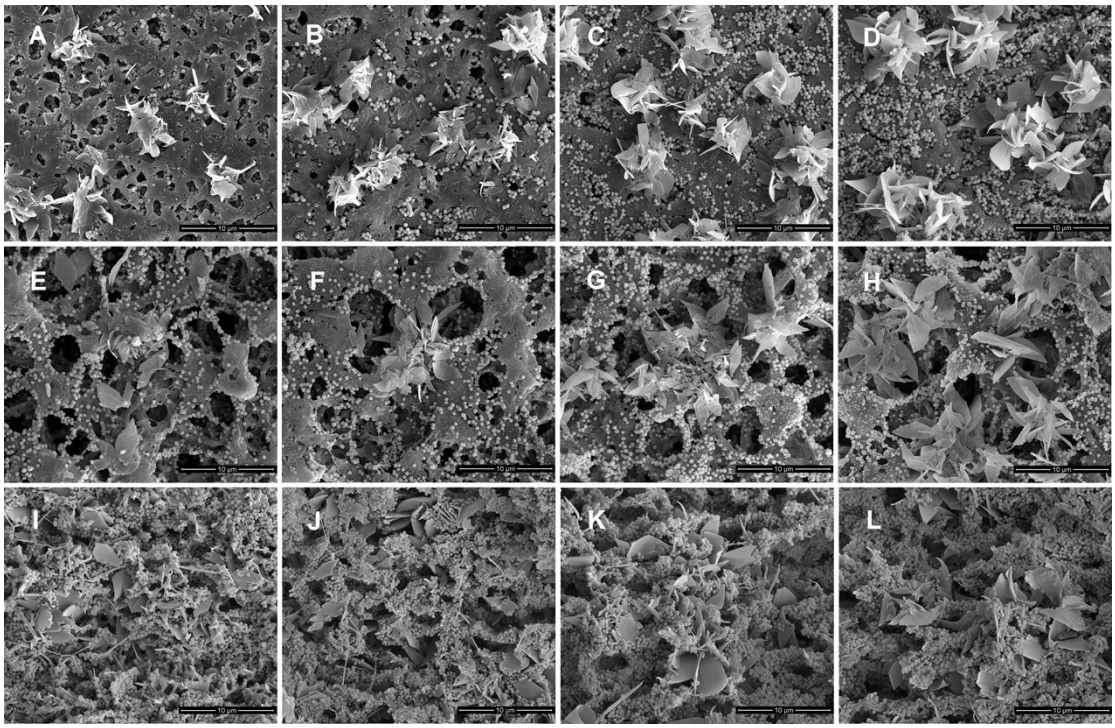

Figure S2. Morphologies and structures of the PVDF/PDA-AgNPs-Cys hybrid membranes: SEM images of the upper surface (A, B, C, D), lower surface (E, F, G, H), and cross-section (I, J, K, L) of the various membranes, M3-1 (A, E, I), M3-2 (B, F, J), M3-3 (C, G, K), and M3-4 (D, H, L).

SEM-EDS mapping analysis of M3-4

For further confirming the distribution of AgNPs and cysteine flowers on the surface and cross-section of the membranes, SEM-EDS mapping was respectively performed and the data was showed in Figure S3. It could be observed that the C, F, N, O, and Ag elements were uniformly distributed on the surface of M3-4 from Figure S3A, while the S element was distributed as clusters for the most. As is known to all, N and O are the characteristic elements of PDA microspheres, Ag element is originated from the deposited AgNPs and S element is from the immobilized cysteine flowers. Therefore, the images confirmed the successful immobilization and uniform distribution of AgNPs and cysteine flowers on the surface of the PVDF/PDA-AgNPs-Cys hybrid membranes. Similarly, as shown in Figure S3C, the AgNPs and cysteine flowers were verified to be uniformly immobilized on the membranes cross-section. Otherwise, the elemental percentage content on the surface and cross-section of the membranes were obtained and exhibited in Figure S3B and D. It can be concluded that the Ag element content on the cross-section was higher than that on the surface, indicating that the silver nitrate solution indeed penetrated into the membrane pores and then was reduced into AgNPs on the cross-section. The S element content on the cross-section was close to that on the surface, further confirming that there were numerous cysteine flowers immobilizing on the cross-section of the PVDF/PDA-AgNPs-Cys hybrid membranes.

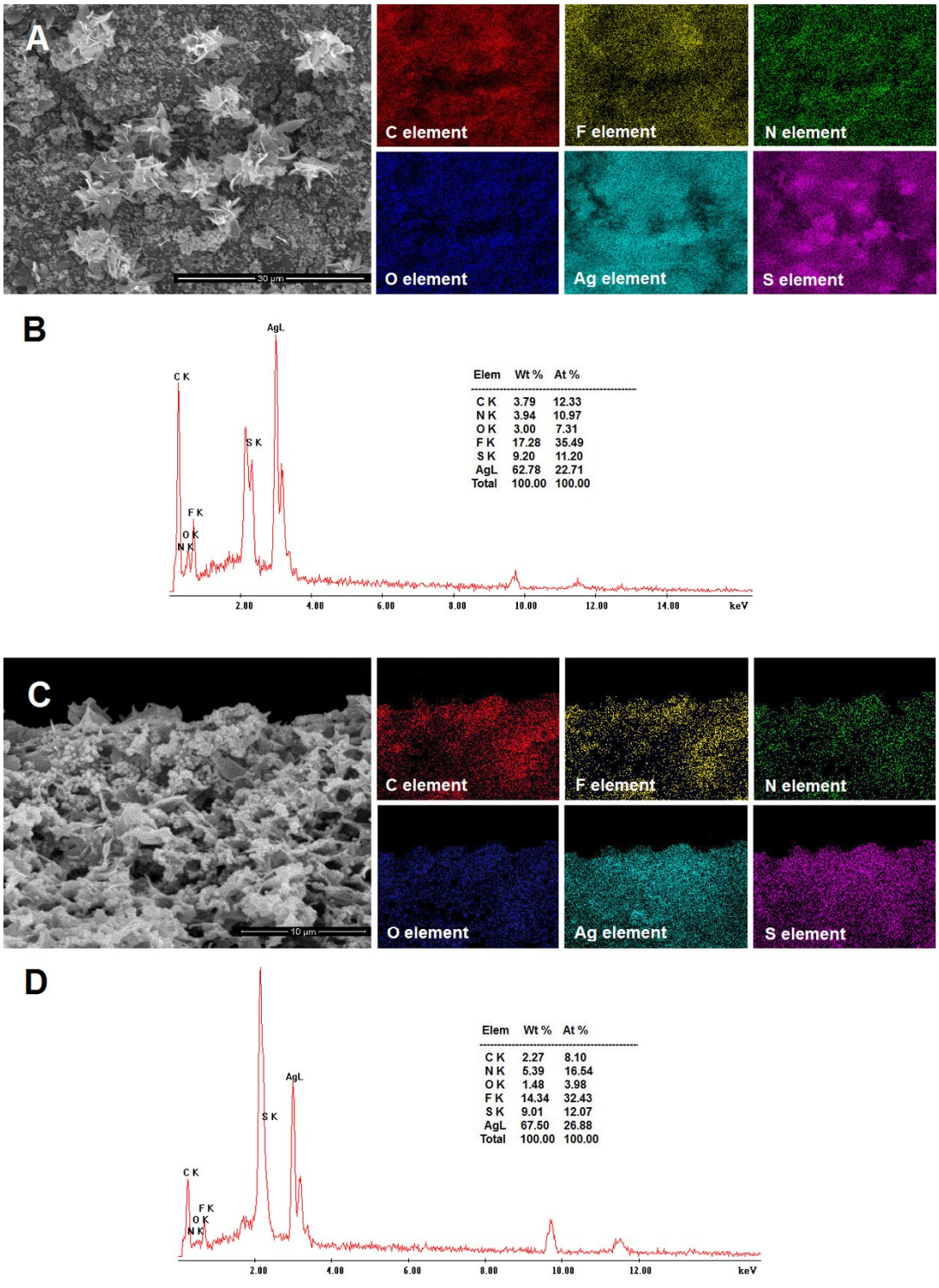

Figure S3. Element distributions of the surface and cross-section of M3-4: distributions of carbon, fluorine, nitrogen, oxygen, silver, and sulphur elements of the surface (A), and the corresponding distributions of peaks and the percentage content (B); distributions of carbon, fluorine, nitrogen, oxygen, silver, and sulphur elements of the cross-section (C), and the corresponding distributions of peaks and the percentage content (D).

The CFU counting method to assess the antibacterial properties

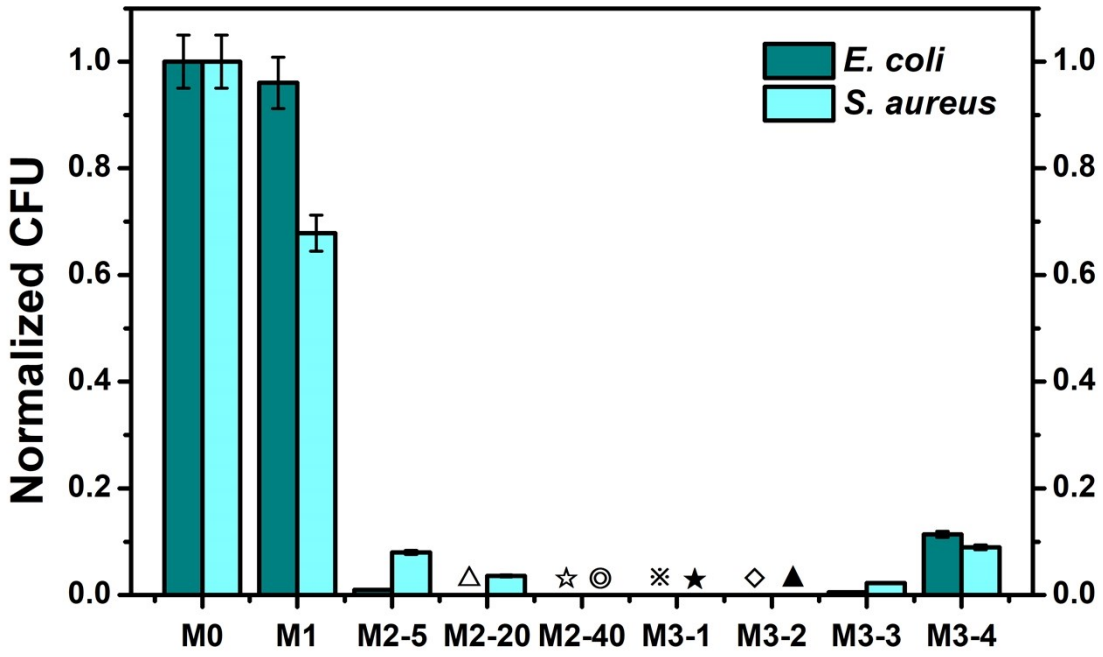

Figure S4. The normalized CFU data of the various membranes: normalized CFU data for *E. coli* and *S. aureus* colonies on the LB agar plates, the seven symbols in place of bars indicated that no colony was present on the membranes.