ASSOCIATED CONTENT

Supporting Information.

Interacting Metal–Insulator–Metal Resonator by Nanoporous Silver and Silk Protein Nanomembranes and Its Water-Sensing Application

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Effects of the refractive index (RI) and the thickness of the silk layer on the resonance

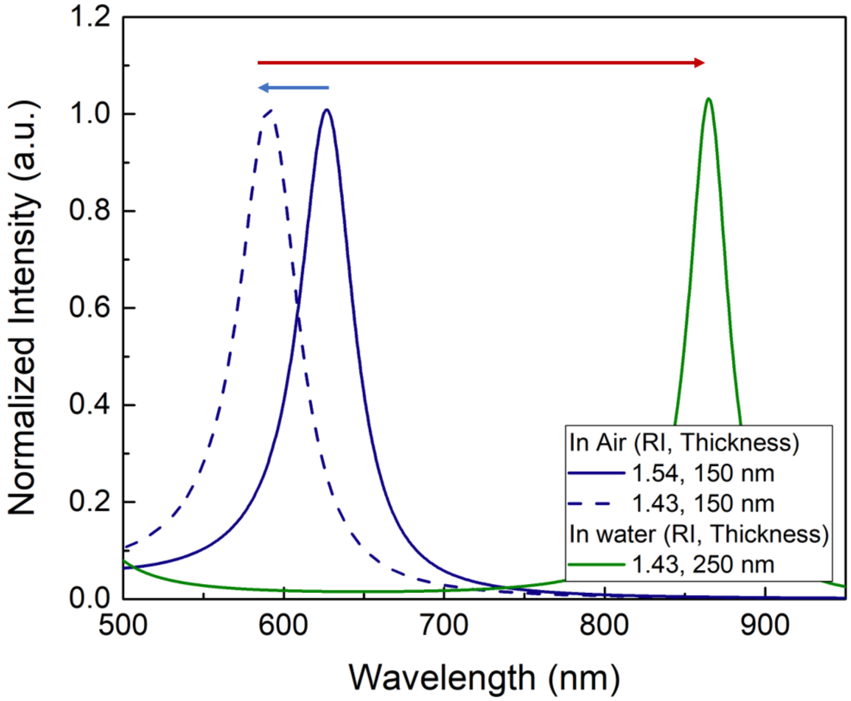

Figure S1. Simulated transmission of the MIM to investigate how the RI and the thickness of the silk layer effect on the resonance.

Effect of the nanopore size on the FP etalon

The effect of the nanopores generated in the top Ag layer on the resonance behavior of the color filter was quantitatively investigated via finite-difference-time-domain (FDTD) simulations in terms of the resonance peak position and full width at half maximum (FWHM). Figures S2a–c show that there were no significant changes in the transmission position of the color filters when a single nanopore from 0 to 14 nm in diameter was introduced into the top Ag layers with thicknesses of 10, 20, and 30 nm. Furthermore, the field localization and the strength of the resonance spectrum directly related to the FWHM of the signal was also not changed by the introduction of a single nanopore of 14-nm diameter (Figure S2d).

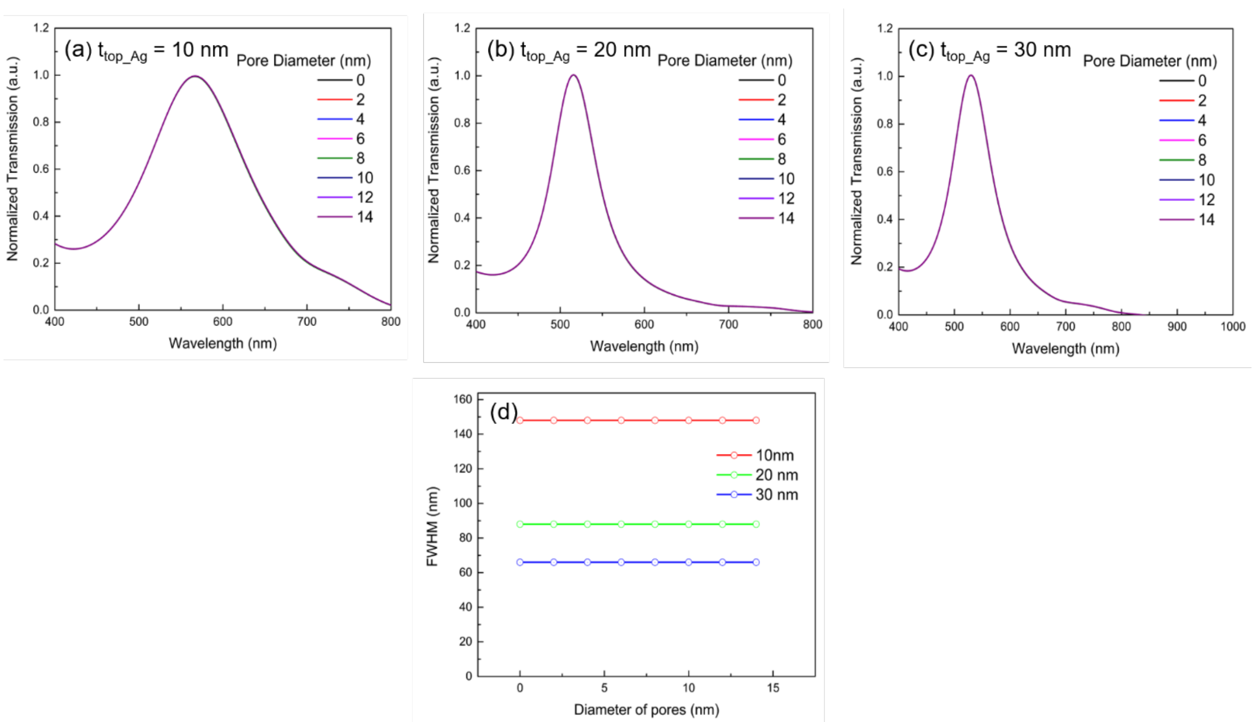

Figure S2. Simulated transmission of the MIM with nanopores of differing dimensions. (a–c) Transmission for different nanopore sizes in the Ag film (film thickness: 10, 20, and 30 nm) color filters. (d) FWHM of the corresponding transmission spectra.

Effect of the numbers of nanopores on the FP etalon

We also investigated the effect of the nanopore density of a certain diameter on the position and the strength of the transmission spectrum. The number of 10-nm pores was increased to 20, and the pores were placed 50 nm from each other on the top surface of the color filters (Figure S3d). Figures S3a–c shows the simulated spectrum has no shift in the peak position for the various numbers of 10-nm nanopores on the color filter with different top Ag layer thickness. (Figure S3e). Furthermore, the FWHM of the transmission spectrum also remains constant for each color filter (Figure S3d).

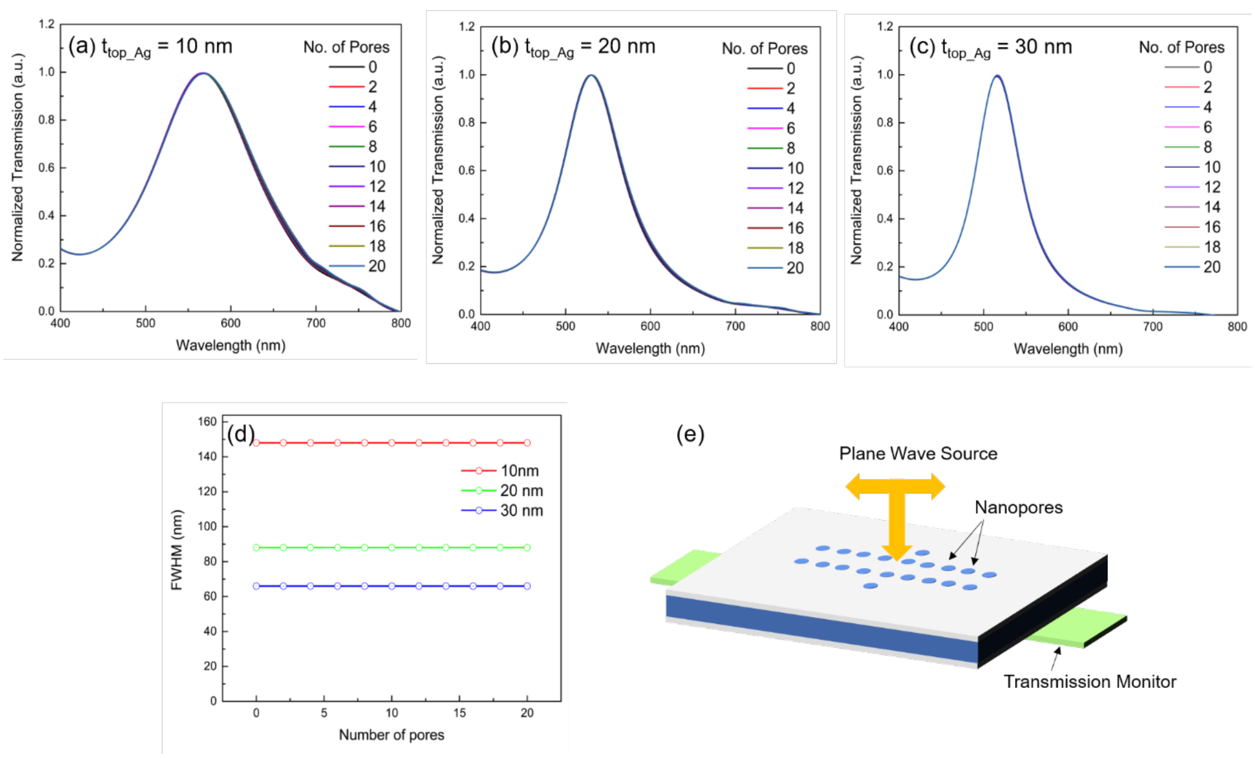

Figure S3. Effect of different numbers of nanopores on the optical properties of the color filter. Simulated transmission peaks of the MIM with different numbers of nanopores in the top silver layer with varying thicknesses: (a) 10, (b) 20, and (c) 30 nm. (d) FWHM of the transmission signal obtained from different color filters with varying numbers of nanopores. (e) Schematic of the simulation setup with nanopores positioned on the top surface of the color filter.

Large nanopores on the MIM cavity

To optimize the size of the nanopores in the top Ag film, which can affect the resonance spectrum of the color film, we introduced 50-nm pores (and larger) into the top Ag film surface of the color filter. The resonance spectra show the extra modes that appear when the pore size is increased from 50 nm, that is, when the dimensions of the nanopores approach the cavity size (Figure S4a–c).

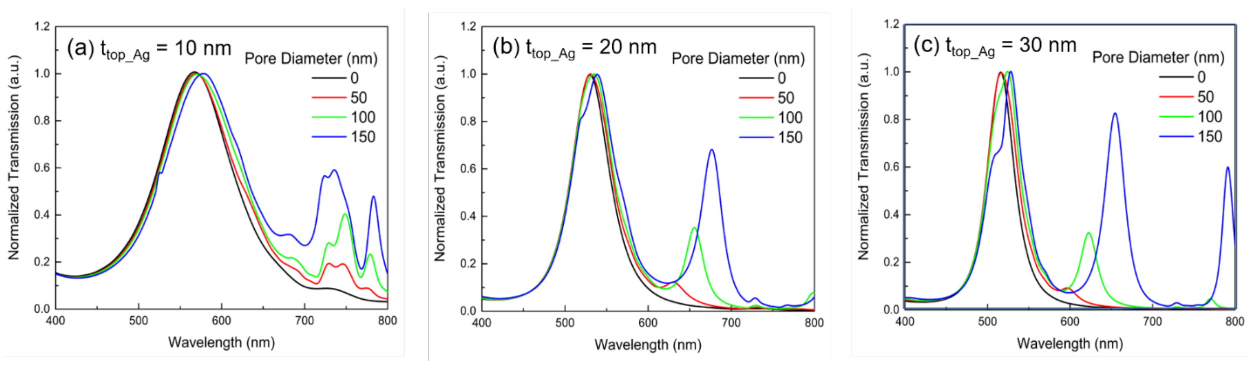

Figure S4. FDTD simulation results for larger nanopores. Simulated transmission spectra of the MIM for the larger diameter of a nanopore in the top silver layer of varying thicknesses: (a) 10, (b) 20, and (c) 30 nm.

Investigation of capillary effects

To investigate the capillary effects, an optical fiber was mounted on an optical bench and initially positioned at 0 mm. The fiber was aligned opposite the MIM resonator. Water was added in such a way that half of the MIM is in the air and the remainder is submerged in water. The transmission spectra were recorded in air and water at 0 mm. At a water level of 2 mm, the wavelength was slightly shifted, which could be due to the meniscus effect. At 3 mm, the spectrum coincided with the air spectrum and remained constant even after the illumination of 2 h; therefore, we concluded that there was no capillary effect.

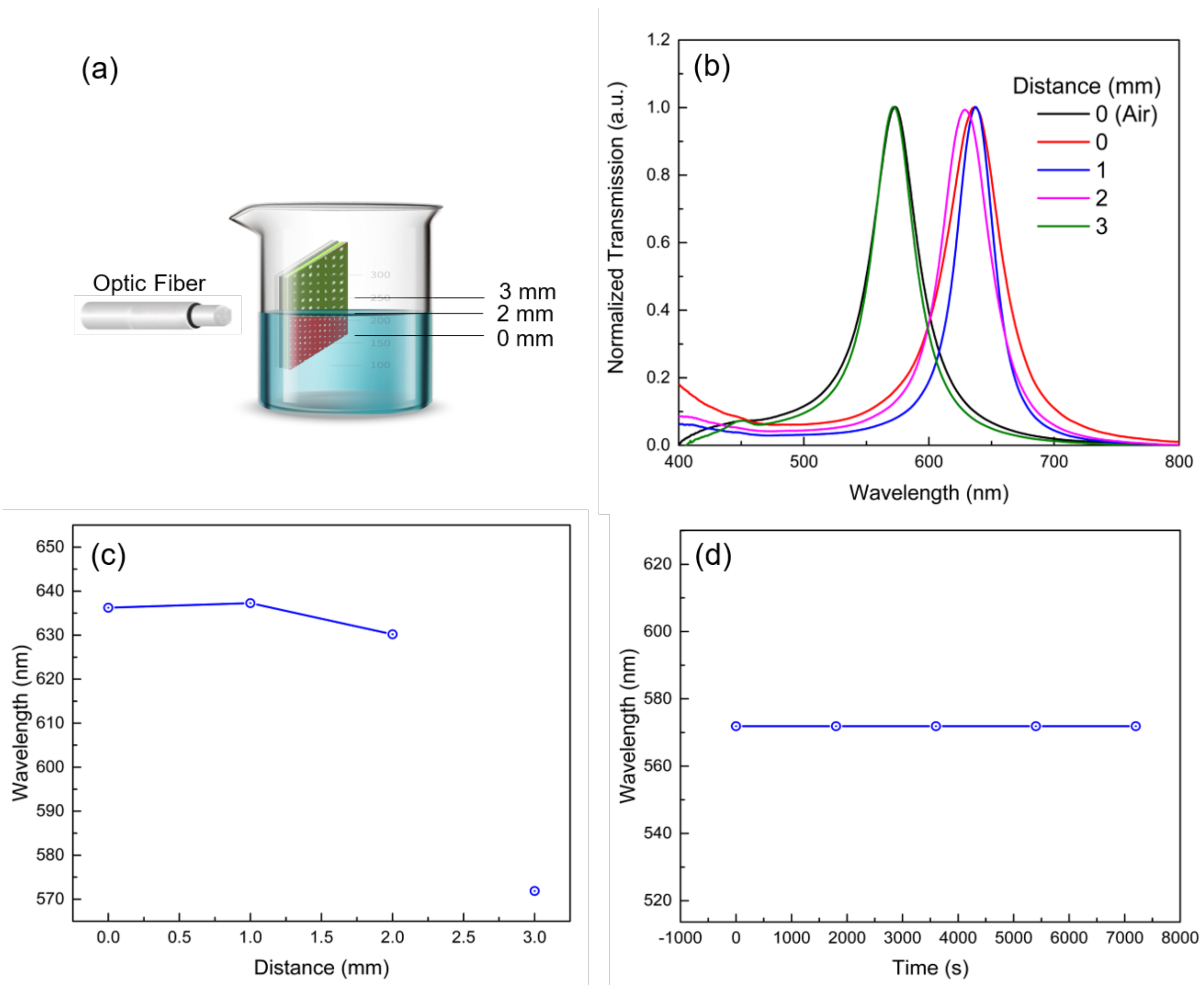

Figure S5. Investigation of the capillary effect. (a) Experimental setup to measure the capillary effect in MIM color filter. (b) Transmission spectra of the MIM at different vertical distances of the optical fiber from the MIM. (c) The wavelength at different vertical distances of the optical fiber from its initial position with respect to the MIM; when the fiber was 1 mm above the water level, the wavelength dropped to the baseline (air), indicating that water does not cause a capillary effect. (d) No change in the wavelength over the time was recorded by the optical fiber at 3 mm.