Supplementary Materials

A Hybrid Metasurface Filter for Multi-Color Visible Light Communication

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Note S1. Material optical constants used in the FDTD simulations

The optical constants of silver were taken from the *CRC Handbook of Chemistry and Physics* and fitted for use in the simulations (**Figure S1**). For the refractive index of poly-Si, SiO_2 and Si, the corresponding Palik data was used directly.

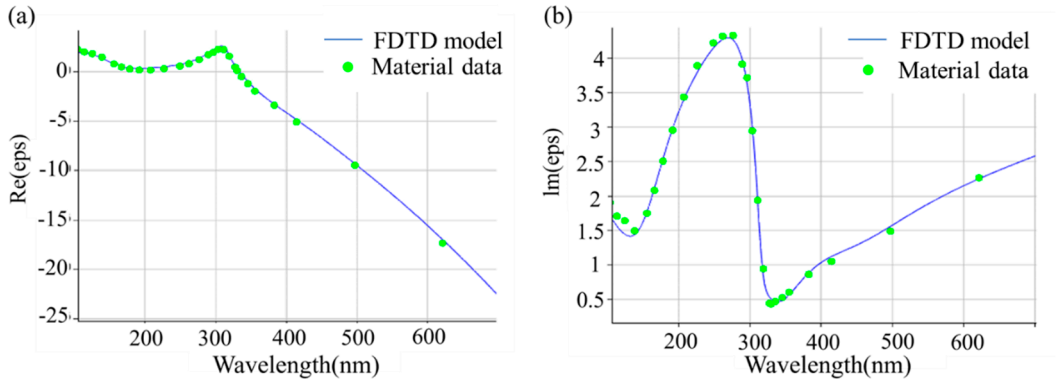


Figure S1. Dielectric permittivity of Ag from CRC experimental data and the corresponding fitted curves in FDTD Solutions: (a) fitted curve of Re(ε); (b) fitted curve of Im(ε).

Note S2. Energy conservation (T + R + A = 1)

The reflection (R), transmission (T), and absorption (A = 1 − T − R) spectra of the three filters are shown in **Figures S2–S4**, confirming that T + R + A ≈ 1 holds across the simulated spectral range.

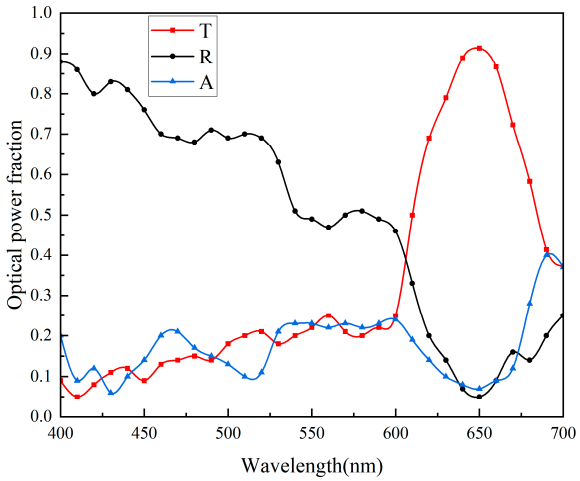


Figure S2. Reflection, transmission, and absorption spectra of the red-channel filter (650 nm), verifying T + R + A ≈ 1.

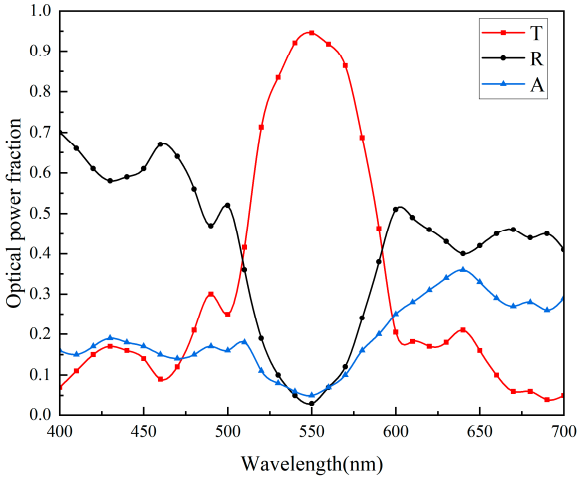


Figure S3. Reflection, transmission, and absorption spectra of the green-channel filter (550 nm), verifying T + R + A ≈ 1.

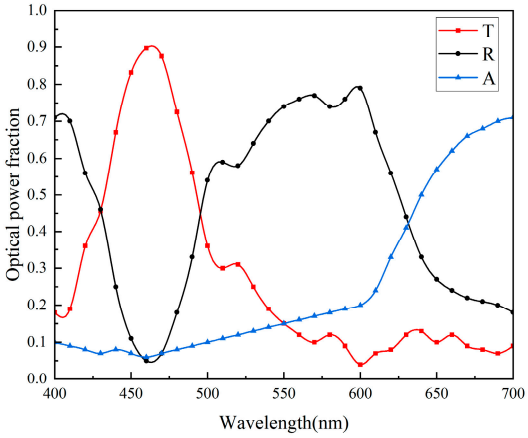


Figure S4. Reflection, transmission, and absorption spectra of the blue-channel filter (450 nm), verifying T + R + A ≈ 1.

Note S3. Complete derivation of the TCMT transmission spectrum and parameter extraction

S3.1 Derivation of Eq. (2) from Eq. (1)

The dual-layer device is modeled as two coupled resonators: a bright LSPR mode (amplitude a_1), which is directly excited by the incident field, and a dark GMR mode (amplitude a_2), which is excited only through near-field coupling. In the steady state under harmonic excitation e^(−iωt), the coupled-mode equations from the main text (Eq. (1)) take the form

$$[\gamma_1 + i(\omega - \omega_1)]a_1 - i\kappa a_2 = \sqrt{\gamma_r 1} \cdot S_i n, (S1a)$$

$$[\gamma_2 + i(\omega - \omega_2)]a_2 - i\kappa a_1 = 0, (S1b)$$

where ω_1 and ω_2 are the resonance angular frequencies, γ_1 and γ_2 the total decay rates ($\gamma_i = \gamma_{r,i} + \gamma_n r_{,i}$), κ the near-field coupling rate, $\gamma_r 1$ the radiative decay rate of the bright mode, and S_in the incident-field amplitude ($|S_{in}|^2$ = power). The output field

obeys the input–output relation

$$S_{\text{out}} = S_{in} - \sqrt{\gamma}_r 1 \cdot a_1. (S2)$$

Solving Eq. (S1b) for the dark-mode amplitude gives

$$a_2 = i\kappa a_1/[\gamma_2 + i(\omega - \omega_2)]. (S3)$$

Substituting Eq. (S3) into Eq. (S1a) yields

$$[\gamma_1 + i(\omega - \omega_1)]a_1 - i\kappa \cdot i\kappa a_1/[\gamma_2 + i(\omega - \omega_2)] = \sqrt{\gamma_r} 1 \cdot S_i n$$

$$\gamma_1 + i(\omega - \omega_1) + \kappa^2/[\gamma_2 + i(\omega - \omega_2)]a_1 = \sqrt{\gamma_r} 1 \cdot S_i n, (S4)$$

where we used $-i\kappa \cdot i\kappa = \kappa^2$. Hence,

$a_1 = \sqrt{\gamma_r} 1 \cdot S_i n/\gamma_1 + i(\omega - \omega_1) + \kappa^2/[\gamma_2 + i(\omega - \omega_2)]$. (S5)

By inserting Eq. (S5) into Eq. (S2) and taking the modulus squared, we obtain the transmission spectrum

$T(\omega) = |S_o ut/S_i n|^2 = |1 - \gamma_r 1/\gamma_1 + i(\omega - \omega_1) + \kappa^2/[\gamma_2 + i(\omega - \omega_2)]|^2$, (S6)

which is exactly Eq. (2) of the main text.

The term $\gamma_r 1/$ ... encodes the Fano interference between the broad bright mode and the narrow dark mode. Within the detuned window the denominator of the κ^2 term is minimized, so the coupling-mediated pathway dominates; the resulting destructive interference suppresses the direct reflection channel, thereby opening the high-transmission transparency window described in the main text.

S3.2 Parameter extraction from FDTD

The model parameters are extracted from full-wave FDTD simulations as follows.

(i) *Isolated resonances.* The isolated LSPR layer and the isolated GMR layer are simulated separately. Their transmission spectra give the resonance wavelengths λ_1 and λ_2 (hence $\omega_i = 2\pi c/\lambda_i$) and the linewidths, from which the total decay rates are obtained as $\gamma_i = \pi c \cdot \Delta\lambda_F WHM, _i/\lambda_i^2$. For the bright mode, the radiative part $\gamma_r 1$ is determined from the depth of the transmission dip and the non-radiative part γ_nr1 from the metal absorption; for the dark GMR mode, $\gamma_2 \approx \gamma_n r2$.

(ii) *Coupled-system fit.* The FDTD transmission spectrum of the full dual-layer device is fitted to Eq. (S6) by nonlinear least squares, using the isolated-layer values of $\omega_{1,2}$ and $\gamma_{1,2}$ as initial guesses and κ as the free parameter (all five parameters may optionally be refined). This yields κ for each channel.

(iii) *Consistency check.* The fit is repeated for several spacer thicknesses t; the extracted κ(t) follows the expected exponential decay $\kappa = \kappa_0 e^{(-t/w)}$, confirming the evanescent near-field nature of the coupling. The fitted curve reproduces the FDTD spectrum with a small residual (RMS error of a few percent).

S3.3 Symbol conventions

The symbols are summarized in Table S1.

Table S1. Symbol definitions used in the TCMT model.

Symbol	Definition
a_1, a_2	complex amplitudes of the LSPR (bright) and GMR (dark) modes
ω_1, ω_2	resonance angular frequencies of Mode 1 and Mode 2 ($\omega_1 \neq \omega_2$ under detuning)
γ_1, γ_2	total decay rates, $\gamma_i = \gamma_r, i + \gamma_n r, i$
γ_r1	radiative decay rate of the bright mode (coupling to the free-space port)
γ_nr,i	non-radiative (ohmic/absorption) decay rate
κ	near-field coupling rate between the two modes
$S_i n, S_o ut$	input and output field amplitudes ($\|S\|^2$ = power)
t	SiO_2 spacer thickness
w	decay length of the evanescent near-field coupling $\left(\kappa = \kappa_0 e^{(-t/w)}\right)$