Dual-Zero-Scattering in Diffusive Transport

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I Background and Challenge

Diffusive metamaterials can tailor heat, mass, and particle transport, but conventional transparency faces a persistent trade-off: hiding an object from the exterior usually produces distorted fields inside the shell.

This work introduces dual-zero-scattering, a regime that simultaneously eliminates scattering in the background medium and within the metamaterial shell, enabling genuinely non-invasive diffusive devices.

II Main Theories

Scattering cancellation

The shell first cancels the far-field disturbance of a parameter-mismatched object. The background region is restored to the same temperature gradient as the homogeneous reference medium.

$$T_2 = A_0 + B r^m \cos\theta + C r^{-m} \cos\theta,$$

Corrective coordinate transformation

A radial mapping linearizes the shell field and prescribes a spatially varying anisotropic conductivity. The result is a transparent shell whose isotherms align with the background.

$$r' = \frac{B}{A_3} r^m + \frac{C}{A_3} r^{-m},$$

Anisotropic conductivity distribution

The transformed shell conductivity is then assigned as a radius-dependent tensor, which straightens the internal isotherms and completes the dual-zero-scattering design.

$$\kappa_2'(r') = \mathrm{diag}\left(\kappa_{rr}\left(m - \frac{2Cmr^{-m}}{A_3 r'}\right),\ \kappa_{\theta\theta}/\left(m - \frac{2Cmr^{-m}}{A_3 r'}\right)\right).$$

III Structures and Applications

Deep-Learning-Enabled Microstructures

A conditional variational autoencoder maps target conductivity tensors to optimized micro-element geometries, enabling large anisotropy and tailored thermal response.

Distinct Functions

Validated devices include transparent thermal sensors, cloaks, and concentrators. The same logic extends to mass diffusion, electrochemical transport, acoustics, optics, and elastodynamics.

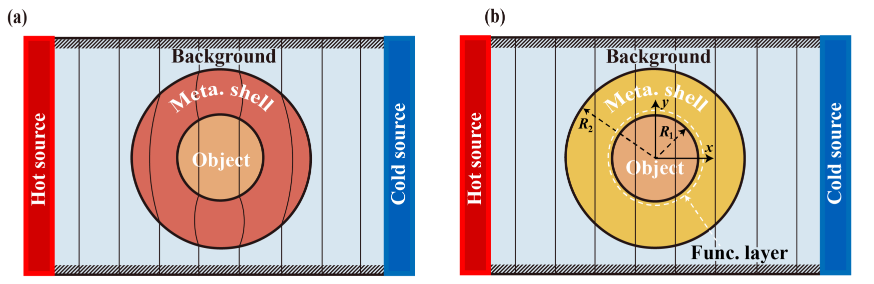

FIG. 1. Conceptual transition from an undisturbed background and bare object to single-zero-scattering and dual-zero-scattering metadevices. The dual-zero design restores both background and shell isotherms.

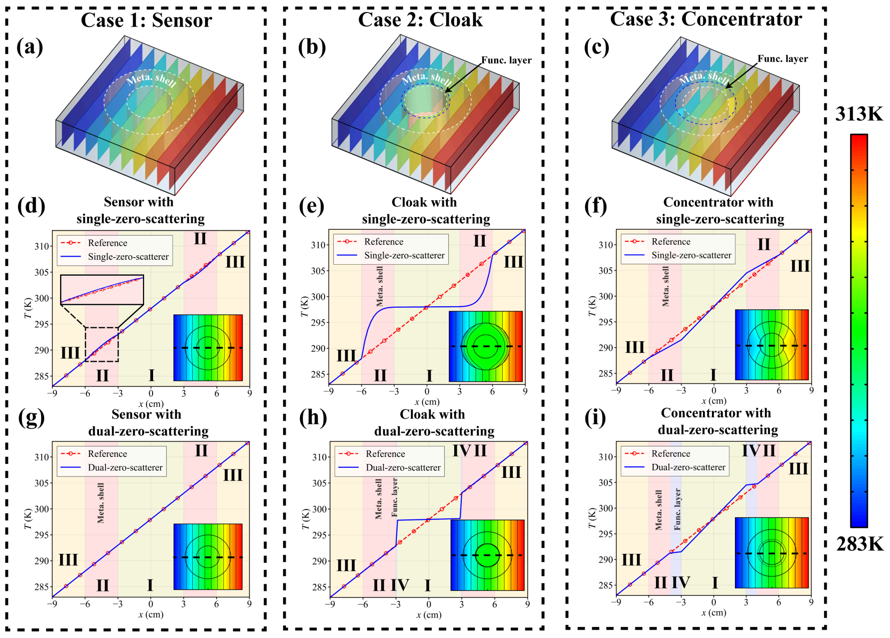

FIG. 2. Finite-element simulations compare single-zero-scattering devices with dual-zero-scattering sensor, cloak, and concentrator designs. Distortion is removed from the shell or confined to the functional layer.

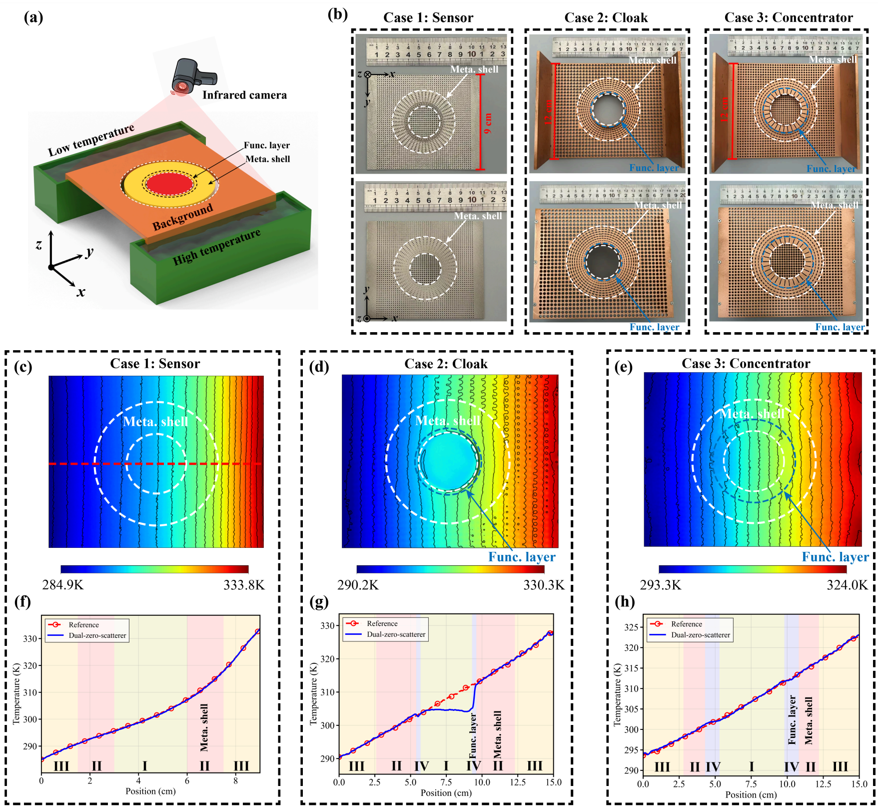

FIG. 3. Experimental implementation using fabricated samples and infrared thermography. Measured temperature profiles closely follow the undisturbed reference, confirming dual-zero-scattering behavior.

Reference

Y. Zhang, J. Liu, L. Xu, P. Jin, F. Marchesoni, and J. Huang, *Dual-Zero-Scattering in Diffusive Transport*, *Phys. Rev. Lett.* **136**, 196901 (2026).

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