# Reinterpreting diffusive constraints: Concentration cloaking via homogenization and pseudoconformal mapping

Yuqian Zhao[1], Yuhong Zhou[1], Peng Jin[2], Ji-ping Huang[1,3]

[1]Department of Physics, Fudan University, Shanghai 200438, China;

[2]Department of Electrical and Computer Engineering, National University of Singapore, Kent Ridge 117583, Republic of Singapore;

[3]College of Science, University of Shanghai for Science and Technology, Shanghai 200093, China

## Introduction

Manipulating mass diffusion is essential for applications ranging from drug delivery to pollution control, yet conventional diffusion cloaks are fundamentally limited in high-diffusivity environments and often require impractical anisotropic materials. Here, we reinterpret rotational convection through homogenization theory and show that it effectively mimics a **concentration near-zero-index (NZI) medium**. By combining this active transport mechanism with **pseudoconformal mapping**, we realize an **isotropic concentration cloak** that **preserves the background field while enabling the cloaked region to respond to external concentration changes in real time**.

## Diffusive NZI Analogy for Concentration Cloaking

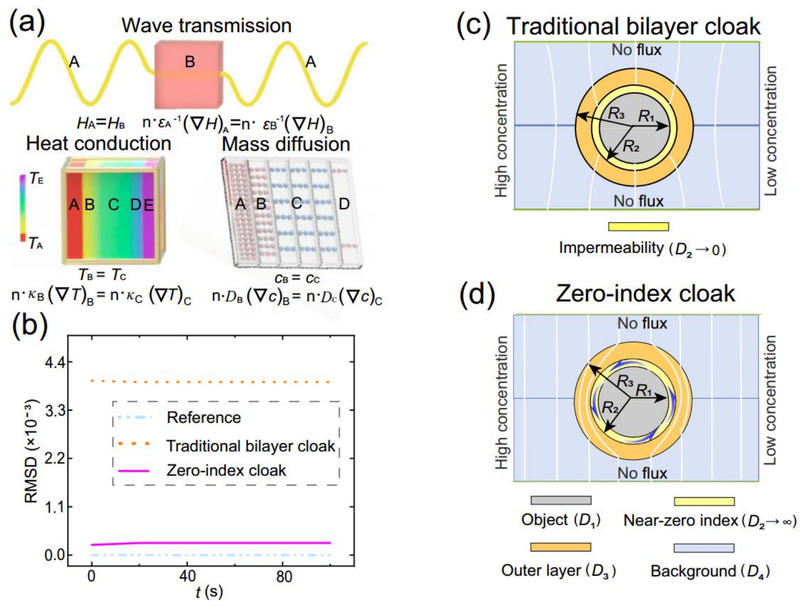


Fig. 1. Diffusive origin of the concentration near-zero-index (NZI) cloak. Rotational convection effectively mimics an infinitely diffusive inner layer, providing a mass-diffusion analog of near-zero-index media. Unlike traditional bilayer cloaks that fail in high-diffusivity backgrounds, the proposed zero-index cloak preserves the background concentration field while remaining physically realizable.

## Experimental Suggestion and Multizone Control

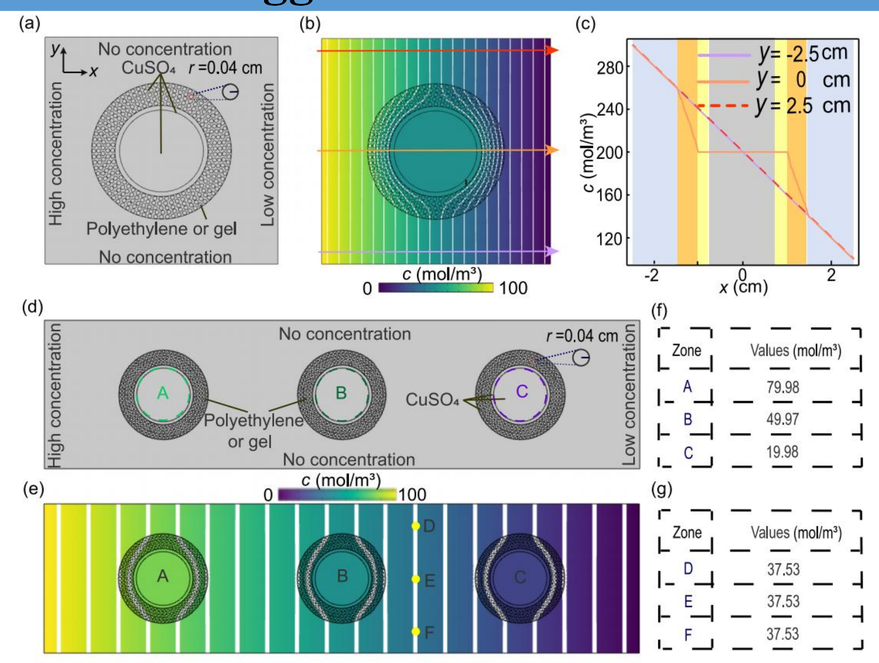


Fig. 4. Experimental suggestion and multizone concentration control. A feasible implementation using perforated structures and rotational flow reproduces the zero-index cloaking effect. The same framework also enables multiple independent concentration microenvironments without disturbing the background field.

## Pseudoconformal Mapping Enables Isotropic Cloaking

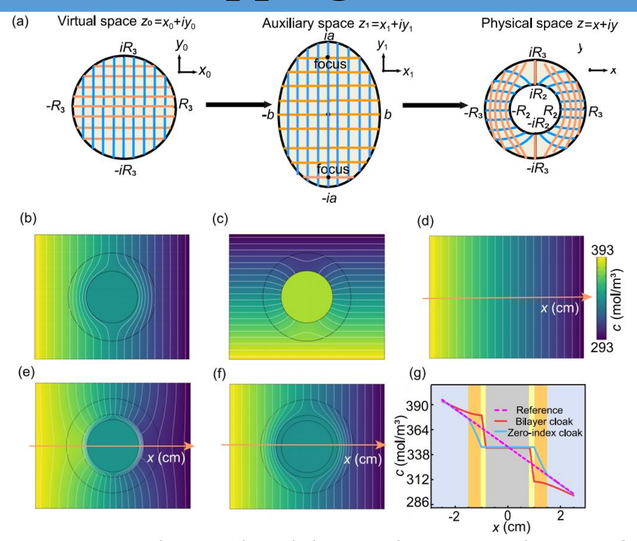


Fig. 2. Isotropic concentration cloaking via pseudoconformal mapping. A unified geometric transformation reveals the duality between the traditional bilayer cloak and the proposed zero-index cloak. In high-diffusivity environments, only the zero-index cloak preserves undistorted background concentration contours.

## Invisibility with Real-Time Concentration Sensing

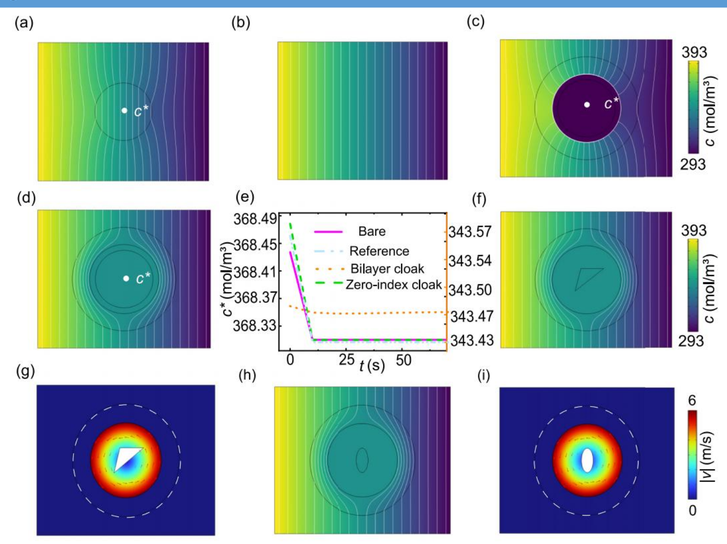


Fig. 3. Cloaking and responsive sensing in transient diffusion. Compared with traditional bilayer cloaks, the zero-index cloak combines background-preserving invisibility with a much faster internal concentration response, while remaining effective for arbitrary object shapes.

## Conclusion.

- We reinterpret rotational convection as a **diffusive near-zero-index analog**, establishing a new route for concentration control in high-diffusivity environments.
- By combining homogenization theory with **pseudoconformal mapping**, we realize an **isotropic concentration cloak** that overcomes the material bottleneck of traditional passive designs.
- Numerical simulations show that the cloak preserves the background concentration field while enabling **real-time environmental sensing** inside the cloaked region, even for arbitrary target shapes.
- A feasible design using **perforated structures and rotating flow** suggests practical applications in multiregion biochemical regulation, pollution control, and high-throughput diffusion screening.

## Reference.

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2. H. H. Tan, **Y. Q. Zhao**, P. Jin, X. Xu, X. C. Zhou, F. Marchesoni, J. P. Huang, Proc. Natl. Acad. Sci. USA 122, e2424421122 (2025).

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