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Multi-physical field null medium: new solutions for the simultaneous control of EM waves and heat flow

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In a recent study, a research group from Taiyuan University of Technology published their findings in the journal *Opto-Electronic Science* with a title "Simultaneously realizing thermal and electromagnetic cloaking by multi-physical null medium." This work introduces a structure that can control simultaneously both electromagnetic waves and heat flow. For the first time, a single structure capable of cloaking both electromagnetic waves and heat flow was experimentally demonstrated. This research offers new solutions for the simultaneous control of electromagnetic waves and heat flow, and advances the hybrid design of electromagnetic compatibility and thermal management, which may have important potentials in e.g. medical applications.

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Electromagnetic (EM) waves and temperature follow completely different physical laws and satisfy distinct physical equations. EM waves are of wave phenomenon that adhere to the wave equation, while the temperature variation is due to diffusion phenomenon and satisfies the Laplace equation. Given the fundamental differences in the differential equations that govern waves and diffusion, the methods, materials, and principles for controlling these two types of physical quantities are also different. Physically, controlling both wave and diffusion phenomena simultaneously is challenging, hence metamaterials are typically divided into two categories: wave metamaterials[1–4] and diffusion metamaterials[5,6]. They employ different design methods, working principles, and control strategies to regulate these two physical phenomena of wave and diffusion.

First we take some potential medical applications as examples. Through thermal cloaking, background thermal noise can be reduced or eliminated, improving the contrast and accuracy of thermal imaging when detecting and diagnosing inflammation, tumors, or other lesions. Thermal cloaking can also help to control more precisely the heat distribution in the treatment area during laser or thermal ablation treatment of tumors, ensuring that the laser or heat energy only acts on tumor tissue and reduces damage to surrounding healthy tissue. Electromagnetic cloaking can help reduce electromagnetic interference, achieving more accurate non-invasive detection, monitoring and imaging (such as MRI), and improving the effect of early disease screening and the

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accuracy of diagnosis. Electromagnetic cloaking can also help to ensure an electronic device implanted into the body will not interfere with the normal operation of electromagnetic imaging or other medical equipment. In many applications, it is necessary to control both EM waves and heat flow simultaneously. In treatments such as laser therapy or thermal ablation, thermal cloaking can reduce the spread of heat, while electromagnetic cloaking ensures that electromagnetic equipment is not interfered with, thereby improving the accuracy of treatment. Multi-modality intelligent diagnosis combining MRI and thermal imaging can achieve more accurate diagnosis while reducing interference and noise. For a medical device implanted in the body, thermal cloaking can prevent the implants from generating unnecessary heat, while electromagnetic cloaking can ensure that these devices do not cause interference when performing electromagnetic imaging, improving the stability and effectiveness of the device.

In highly integrated chip systems, a structure capable of cloaking both EM waves and heat flow is required to achieve EM compatibility and efficient thermal management[7–9], that is, to ensure that electronic components are not interfered by surrounding EM waves while not affecting the transmission of surrounding EM waves, and also to ensure that the electronic components do not affect the distribution of the surrounding temperature while not being impacted by the heat flow caused by the surrounding temperature gradient. In addition, electromagnetic heat issues are prevalent in high-power antenna radomes and microwave energy converters. Controlling both EM waves and heat flow is essential in these structures. Therefore, achieving control over both EM waves and temperature is a research topic of significant importance. However, there is still a need for a theoretical design method that can simultaneously control EM waves and heat flow. Additionally, there is a scarcity of metamaterials capable of controlling both wave and diffusion phenomena.

To address the current lack of design methods and effective metamaterials for the simultaneous control of EM waves and heat flow, in a recent work published in *Opto-Electronic Science*, DOI: 10.29026/oes.2024.230027, Dr. Yichao Liu *et al.* proposed a double-field surface transformation theory[10] that can control both EM waves and temperature simultaneously. With the help of this theory, the problem of controlling EM waves and heat flow can be transformed into a geometric projection design problem. Through standardized black-box design steps, structures with different functions for controlling EM waves and heat flow can be designed, all of which only need to be implemented through a dual-physical field null medium composed of staggered copper plates and expanded polystyrene (EPS) boards. They also designed and experimentally realized an effective cloaking structure for both EM waves and heat flow. The simulation and measurement results are highly consistent, indicating that the dual-physical field cloaking structure can simultaneously guide EM waves and heat flow around the hidden area without causing any disturbance to the external EM field and temperature distribution. This research is a continuation of the single physical field null medium[11–14], providing new theoretical design methods and material selection schemes for the simultaneous control of EM waves and temperature.

The proposal of the multi-physical field null medium inspires further research. For more specific application scenarios, we look forward to more flexible multi-physical field control structures and materials that can be applied to more complex working environments, such as being able to adapt to different sizes and shapes, achieving dual-polarization operation and realizing frequency selection functions.

References

1. He SL, Cui YX, Ye YQ et al. Optical nano-antennas and metamaterials. *Mater Today* **12**, 16–24 (2009).
2. Guo TB, Zhang Z, Lin ZJ et al. Durable and programmable ultrafast nanophotonic matrix of spectral pixels. *Nat Nanotechnol* (2024).
3. Cao T, Lian M, Chen XY, Mao LB, Liu K et al. Multi-cycle reconfigurable THz extraordinary optical transmission using chalcogenide metamaterials. *Opto-Electron Sci* **1, 2**, 10010 (2022).
4. Berhe AM, As'ham K, Al-Ani I et al. Strong coupling and catenary field enhancement in the hybrid plasmonic metamaterial cavity and TMDC monolayers. *Opto-Electron Adv* **7**, 230181 (2024).
5. Wang J, Dai GL, Huang JP. Thermal metamaterial: fundamental, application, and outlook. *iScience* **23**, 101637 (2020).
6. Yang S, Wang J, Dai GL et al. Controlling macroscopic heat transfer with thermal metamaterials: theory, experiment and application. *Phys Rep* **908**, 1–65 (2021).
7. Wu B, Qian G, Yan YY et al. Design of interconnected carbon fiber thermal management composites with effective EMI shielding activity. *ACS Appl Mater Interfaces* **14**, 49082–49093 (2022).
8. Shi SH, Dai MY, Tao XY et al. 3D printed polylactic acid/graphene nanocomposites with tailored multifunctionality towards superior thermal management and high-efficient electromagnetic interference shielding. *Chem Eng J* **450**, 138248 (2022).

9. Zhang Y, Zuo XP, Zhang S et al. Flexible multifunctional magnetic-conductive Janus nanocomposite films towards highly-efficient electromagnetic interference shielding and thermal management. *Compos Sci Technol* **256**, 110756 (2024).
10. Liu YC, Ma XM, Chao K et al. Simultaneously realizing thermal and electromagnetic cloaking by multi-physical null medium. *Opto-Electron Sci* **3**, 230027 (2024).
11. Sun F, Liu YC, He SL. Surface transformation multi-physics for controlling electromagnetic and acoustic waves simultaneously. *Opt Express* **28**, 94–106 (2020).
12. Sun F, He SL. Optical Surface Transformation: changing the optical surface by homogeneous optic-null medium at will. *Sci Rep* **5**, 16032 (2015).
13. Liu YC, Sun F, He SL. Fast adaptive thermal buffering by a passive open shell based on transformation thermodynamics. *Adv Theory Simul* **1**, 1800026 (2018).
14. Sun F, He SL. Homogenous optic-null medium performs as optical surface transformation. *Prog Electromagn Res* **151**, 169–173 (2015).

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