# Periodic composites: Quasi-uniform heat conduction, Janus thermal illusion, and thermal rectification with illusion

L. J. Xu, C. R. Jiang, J. Shang, R. Z. Wang and J. P. Huang

Department of Physics, Fudan University, Shanghai, 200433, China

Collaborative Innovation Center of Advanced Microstructures, Nanjing 210093, China

## I. Introduction

It is known that both wave and diffusion are two important methods for transferring energy or matter, which are described by wave and diffusion equations, respectively. In contrast to wave equations [1–3], it is still far from being satisfactory to apply periodicity to design materials that are described by diffusion equations [4]. By developing an effective medium theory including periodicity, here we experimentally show that non-uniform media can exhibit quasi-uniform heat conduction. This provides capabilities in proposing Janus thermal illusion and illusion thermal rectification which may have potential applications for military.

## II. Method

We consider a two-dimensional binary composite, where many elliptic particles of thermal conductivity $\kappa_1$ and area fraction $p$ are periodically embedded in a matrix of $\kappa_2$ and $1-p$. All the particles have their long (or short) axes aligned along $x$ (or $y$) direction, whose shape factors characterizing the shape of the particles are $L_i$ with $i = x$ or $y$ along $x$ (or $y$) direction. Here, $L_x + L_y = 1$ and $L_x = L_y = 0.5$ for circular particles. We denote the local thermal gradient field inside the particles by $\nabla T_1$, and that inside the matrix by $\nabla T_2$.

$$\kappa_e = \frac{p\kappa_1\langle\nabla T_1\rangle + (1-p)\kappa_2\langle\nabla T_2\rangle}{p\langle\nabla T_1\rangle + (1-p)\langle\nabla T_2\rangle} \quad (1)$$

$$\langle\nabla T_1\rangle = \frac{\kappa_2}{L_i\kappa_1 + (1-L_i)\kappa_2}\langle\nabla T_2\rangle \quad (2)$$

## III. Quasi-uniform heat conduction

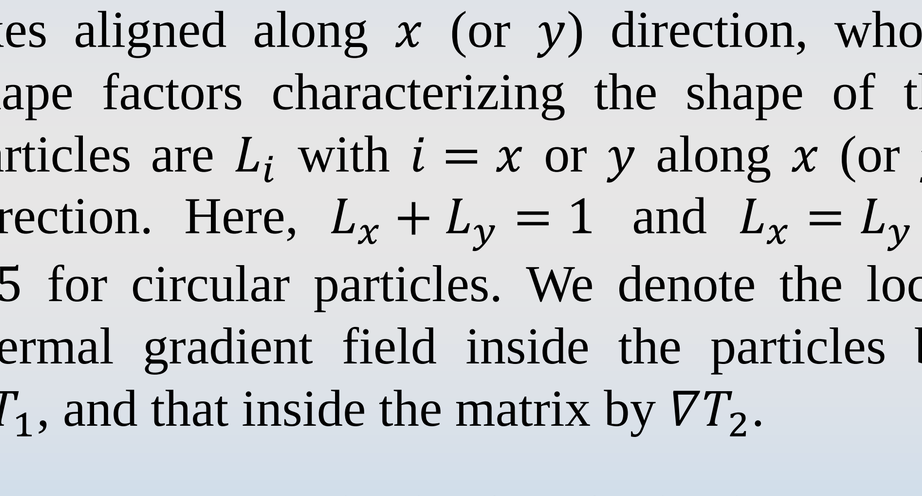


Fig. 1 Six samples illustrating the concept of quasi-uniform heat conduction.

## IV. Janus thermal illusion

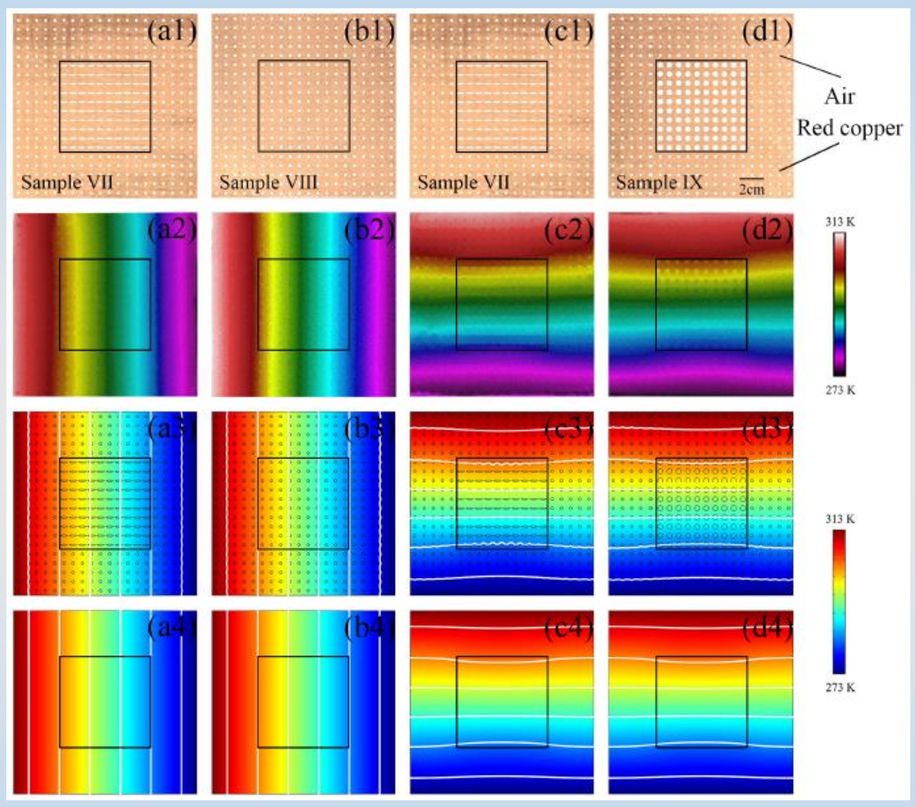


Fig. 2 Experimental and simulation results of Janus thermal illusion.

## V. Illusion thermal diode

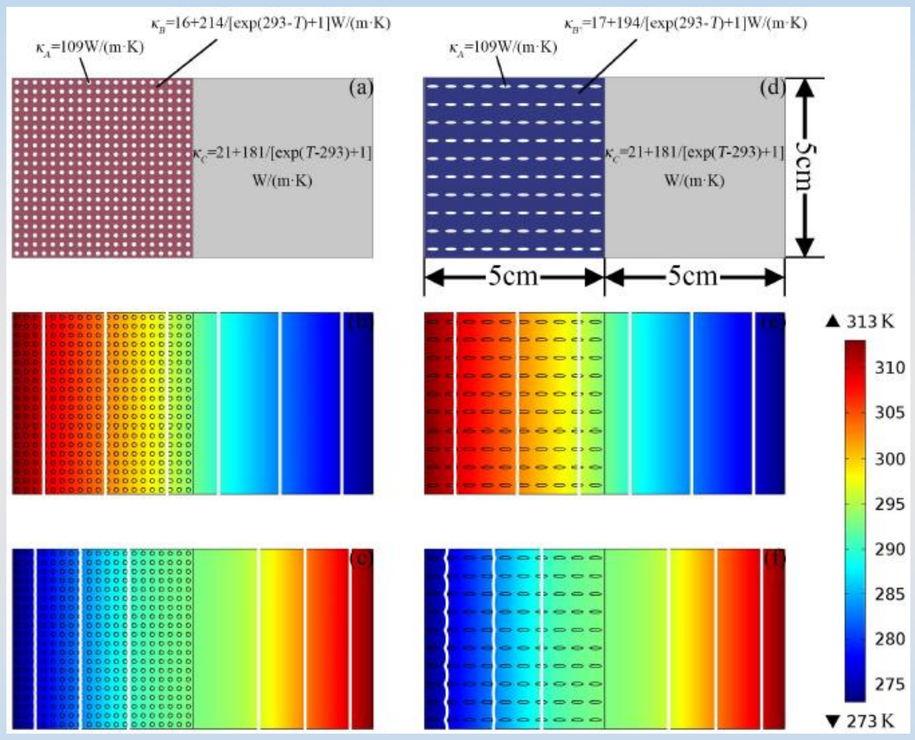


Fig. 3 Simulation results of illusion thermal diode.

## VI. Conclusion

To sum up, our work not only opens a door for designing novel periodic composites in thermal camouflage and heat rectification, but also holds for achieving similar composites in other disciplines like electrostatics, magnetostatics and particle dynamics.

## Reference

[1] E. Yablonovitch, Phys. Rev. Lett. **58**, 841 (1987).
[2] M. M. Sigalas and E. N. Economou, Journal of Sound and Vibration **158**, 382 (1992).
[3] M. Maldovan, Phys. Rev. Lett. **110**, 025902 (2013).
[4] G. Q. Gu and K. W. Yu, J. Phys. D: Appl. Phys. **30**, 1523 (1997).