Transformation-Invariant Metamaterials and Thermal Chameleonlike Rotators: Theory and Experiment

Fubao Yang, Boyan Tian, Liujun Xu, and Jiping Huang

Department of Physics, State Key Laboratory of Surface Physics, and Key Laboratory of Micro and Nano Photonic Structures (MOE), Fudan University, Shanghai 200433, China

I Introduction

Transformation thermotics[1] has achieved great success till now, and the metamaterials based on it have also yielded fruitful results. However, the lack of intelligence is a sore point for transformation-thermotics-based metamaterials. They will fail if the backgroud materials changes. To overcome this problem, we propose a different mechanism[2], which is to use transformation-invariant materials to improve intelligence.We theoretically design thermal rotator as an example to demonstrate the intelligence of designed metamaterials, and both simulation and experiment results confirm our theory.

II Materials and Methods

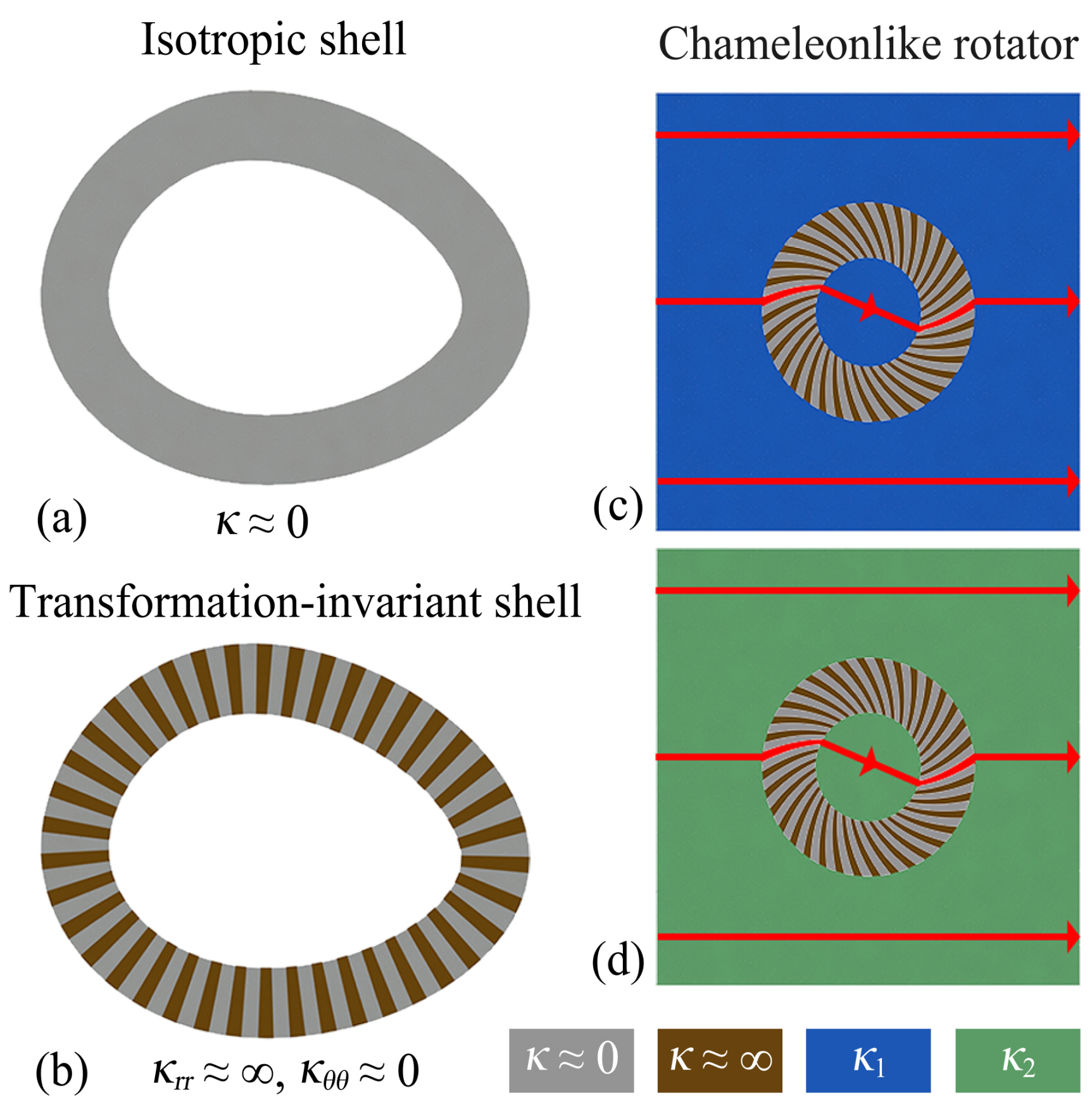

Fig. 1 Schematic diagram of transformation-invariant materials and thermal chameleonlike rotator.

As shown in Fig. 1 (a,b), transformation-invariant materials are highly anisotropic materials, whose thermal conductivity is diag(k_{rr},$k_{\theta\theta}$) = diag(∞,0) . Such materials do not its eigenvalues no matter what coordinate transformation is applied to it, which means its original character is unchanged after transformation. For 2D macroscopic heat transfer system, theory proves that such materials are characterized by adaptive response to changes in the background, just like chameleons. As an application of this theoretical method, an intelligent thermal rotator was designed by rotating the transformation invariant material, as shown in Fig. 1 (c,d), whose thermal conductivity is

$$\boldsymbol{\kappa} = \begin{pmatrix} \kappa_{rr} & \kappa_{rr}\dfrac{r'\theta_0}{R_2 - R_1} \\ \kappa_{rr}\dfrac{r'\theta_0}{R_2 - R_1} & \kappa_{rr}(\dfrac{r'\theta_0}{R_2 - R_1})^2 + \kappa_{\theta\theta} \end{pmatrix}$$

where $R_1$and R_2 are inner and outer radii of the shell, θ_0 is rotation angle.

III Results

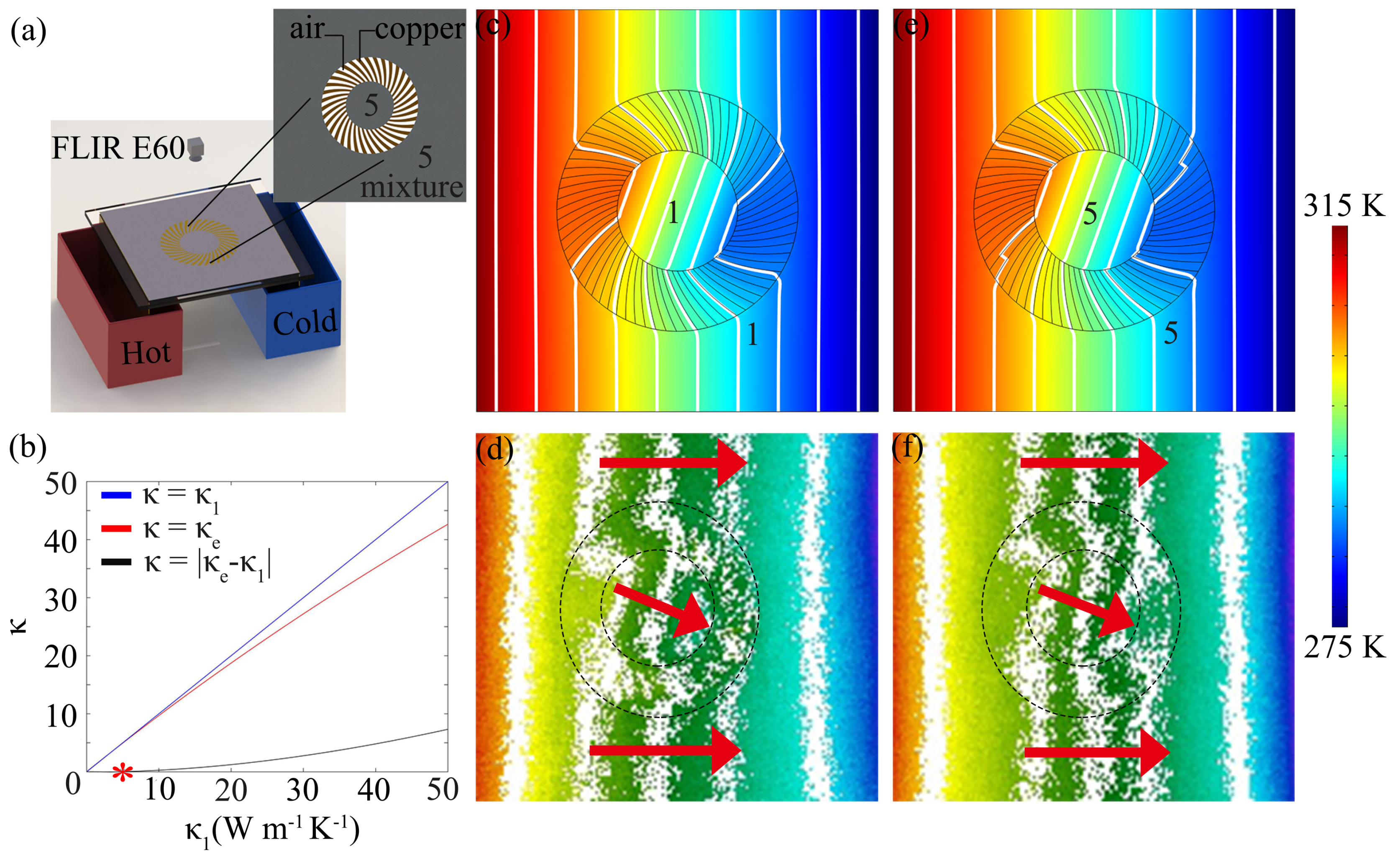

Fig. 2 Simulation and experimental results of chameleonlike rotator.

Fig. 2 (a) is a diagram of the experimental apparatus.To realize highly anisotropic parameters, we use air and copper as transformation-invariant materials, and fabricated a multilayer composite structure to realize a thermal rotator. Because the transformation-invariant material requires a high degree of anisotropy relative to the background, the rotator we make whose thermal conductivity is diag(200, 0.052) W m^{-1}K^{-1} can only work in backgrounds with thermal conductivity between 1 and 5 W m^{-1}K^{-1} after calculation. Experiment results are consistent with the simulation results, as shown in Fig. 2 (c-f). The background is colloidal materials obtained by mixing silica gel and white copper powder, which is determined by the Bruggeman formula.

IV Conclusion

- The proposed meta-device made of transformation-invariant metamaterials can work in different backgrounds.
- Such designed meta-device avoids remanufacturing if background changes, which saves time and labor.
- This scheme improves the intelligence of traditional thermal metamaterials, and can be extended to other fields.

Reference

[1] C. Z. Fan, Y. Gao, and J. P. Huang, Shaped graded materials with an apparent negative thermal conductivity, Appl. Phys. Lett. **92**, 251907 (2008).

[2] F. B. Yang, B. Y. Tian, L. J. Xu, and J. P. Huang, Experimental demonstration of thermal chameleonlike rotators with transformation-invariant metamaterials, Phys. Rev. Appl. **14**, 054024 (2020).

Jiping Huang's research group
Department of Physics
Fudan University

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