Temperature-Dependent Transformation Multiphysics and Ambient-Adaptive Multiphysical Metamaterials

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Introduction. Recent advances in metamaterials and metadevices in diffusion systems [1,2] make it possible to control diffusive fields according to human preference and will. Here, we theoretically establish a temperature-dependent transformation method for controlling multiphysics whose intrinsic physical parameters depend on temperature. Finite-element simulations demonstrate perfect thermoelectric cloaking, concentrating, and rotating performance. Two practical applications are designed with nonlinear transformation. One is an ambient-responsive cloak-concentrator device ; the other is an improved thermoelectric cloak with simultaneous near-thermostat performance inside.

Theory. At a steady state with local equilibrium, the governing equations of TE transport are expressed as:

$$\nabla \cdot \boldsymbol{J} = 0,$$

$$\nabla \cdot \boldsymbol{J_Q} = -\nabla \mu \cdot \boldsymbol{J},$$

$$\boldsymbol{J} = -\boldsymbol{\sigma}(T) \cdot \nabla \mu - \boldsymbol{\sigma}(T)\boldsymbol{S}(T)\nabla T,$$

$$\boldsymbol{J_Q} = -\boldsymbol{\kappa}(T) \cdot \nabla T + T\boldsymbol{S}^{\tau}(T)\boldsymbol{J}.$$

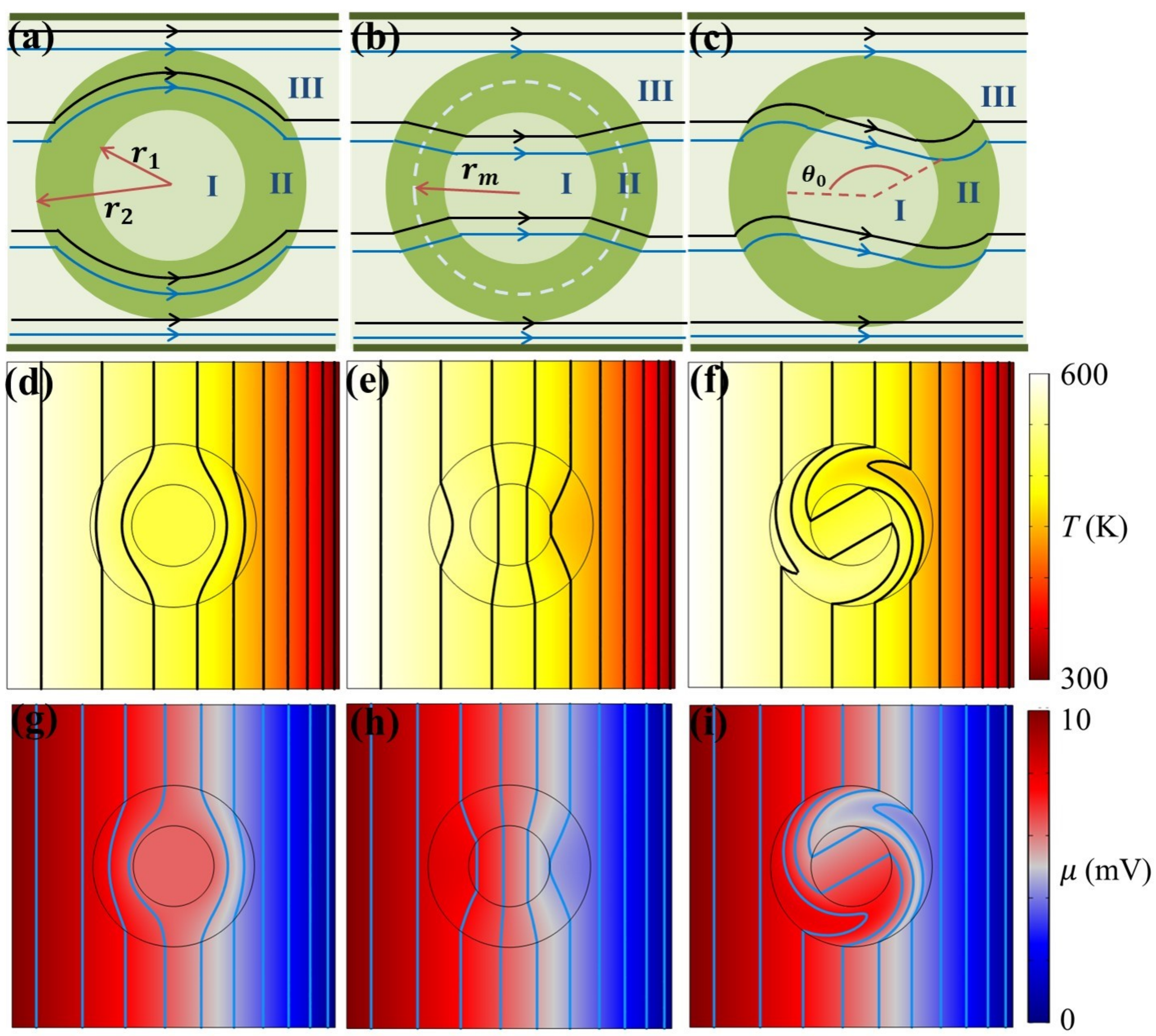
Using the temperature-dependent transformation theory for the thermoelectric control equation, considering the temperature-dependent material parameters, the transformed thermal conductivity, electrical conductivity and Seebeck coefficient can be written as:

$$\boldsymbol{\kappa}'(T) = \frac{\boldsymbol{A}\boldsymbol{\sigma}(T)\boldsymbol{A}^{\tau}}{\det \boldsymbol{A}},$$

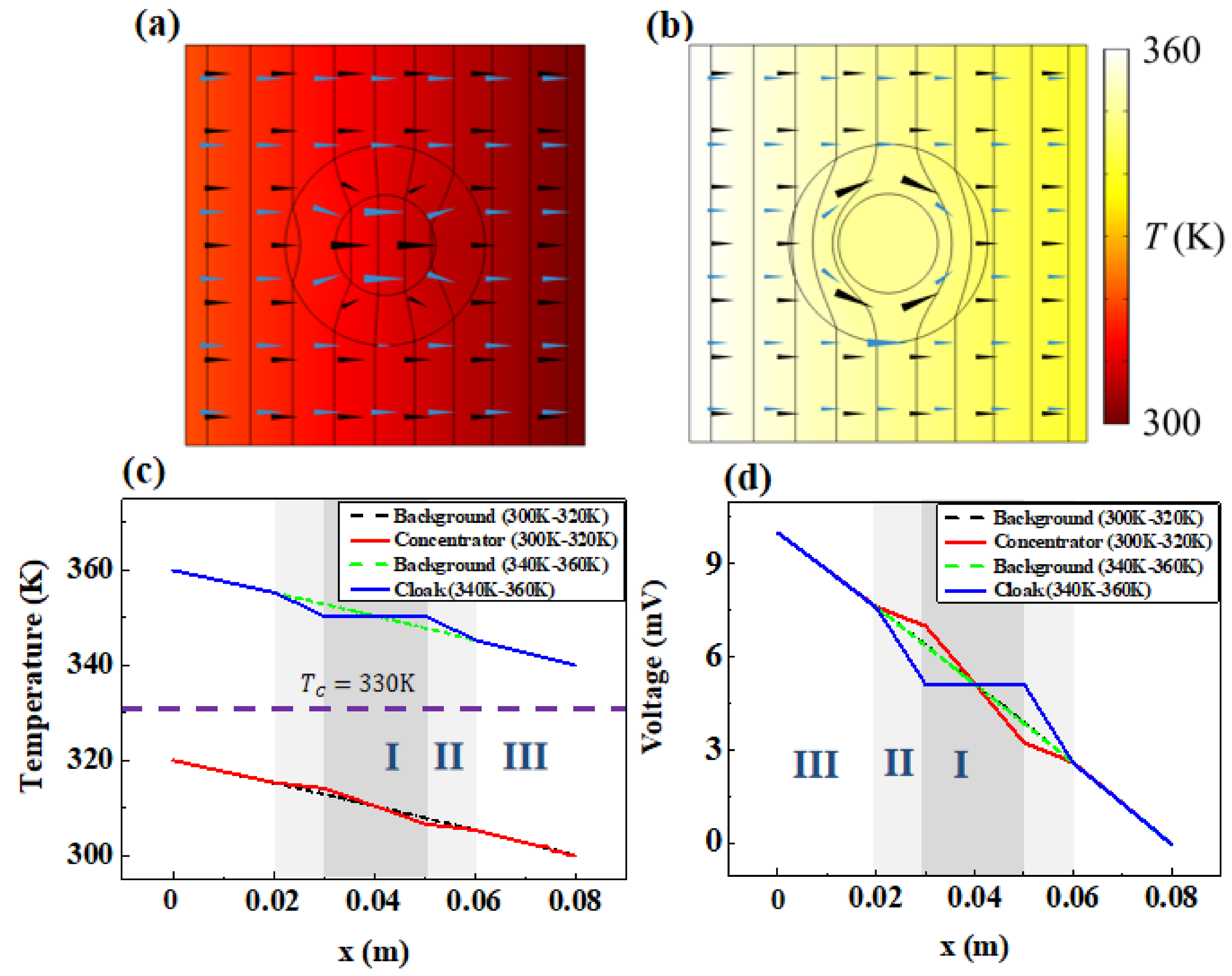
$$\boldsymbol{\sigma}'(T) = \frac{\boldsymbol{A}\boldsymbol{\kappa}(T)\boldsymbol{A}^{\tau}}{\det \boldsymbol{A}},$$

$$\boldsymbol{S}'(T) = \boldsymbol{A}^{-\tau}\boldsymbol{S}(T)\boldsymbol{A}^{\tau}.$$

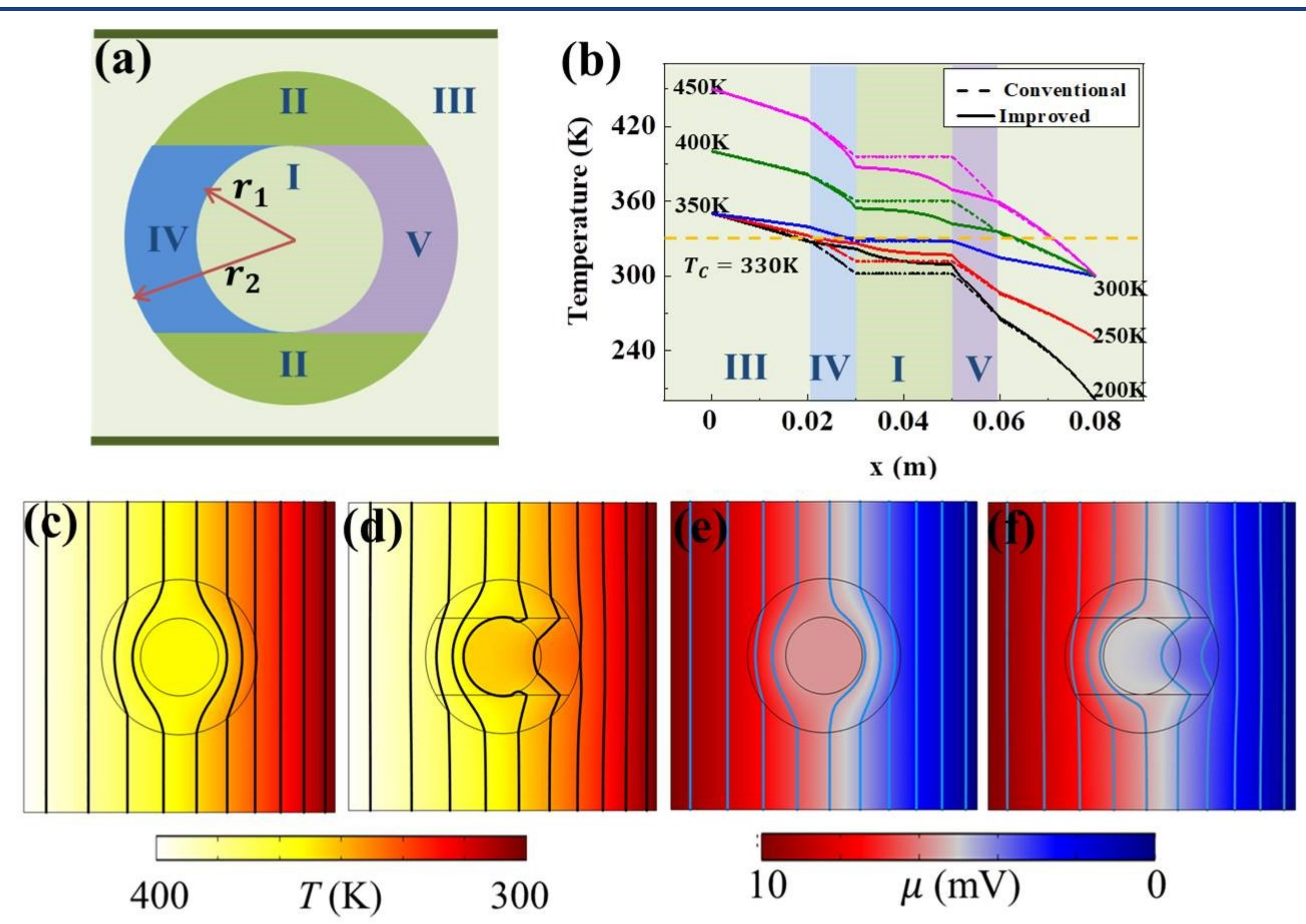
Based on these parameters, thermoelectric cloaks, concentrators, and rotators can be designed.



Simulation-1. The structure of thermoelectric cloak , concentrator, rotator are depicted in (a)-(c), simulation results are shown in (d) -(i) . (d)-(f) Simulation results of temperature distribution, and (g)-(i) simulation results of potential distribution, corresponding to (a)-(c).



Simulation-2. Ambient-responsive cloak-concentrator. (a)-(b) Simulation results of the thermoelectric cloak-concentrator. (c) and (d) are the temperature and voltage curves of the center lines extracted from simulation results in (a) and (b).



Simulation-3. Improved thermoelectric cloak. (c) -(e) Temperature and potential distributions of a conventional thermoelectric cloak, respectively. (d) -(f) Temperature and potential distributions of the improved thermoelectric cloak .

Conclusion.

1. Established temperature-dependent transformation thermoelectrics.
2. Designed temperature-dependent thermoelectric cloaks, concentrators, and rotators.
3. Designed two kinds of practical devices: ambient-responsive cloak-concentrator and improved thermoelectric cloak.

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