# Thermal-wave diode

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Based on the spatiotemporal modulation of thermal conductivity and volumetric heat capacity (Eqns. (1a) and (1b)), we propose a thermal-wave diode (Fig. 1) characterized by the rectification of the heat currents carried by thermal waves [1]. By transforming Fourier's law for the heat flux and the diffusion equation for the temperature into equations with constant coefficients (Eqns. (2a) and (2b)), it is shown that: (i) the rectification effect is generated by the simultaneous wavelike modulation of both thermal properties, such that it disappears in the absence of either of them, and (ii) the rectification factor can be optimized and tuned by means of the speed and phase difference of the variations of the heat capacity and thermal conductivity. High rectification factors, greater than 86%, are obtained for lower frequencies driving the propagation of thermal waves (Figs. 2(a) and 2(b)). The proposed thermal-wave diode is thus analogous to its electronic counterpart operating with modulated electrical currents and can open a vista for developing different types of thermal-wave logic components [2].

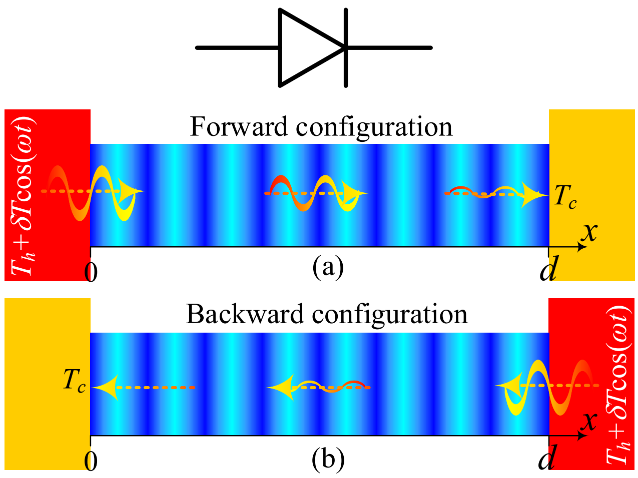


**Fig. 1.** Scheme of a thermal-wave diode operating in the (a) forward and (b) backward configurations. Arrows along with their amplitudes indicate the propagation direction and intensity of the thermal waves generated by the excitation $\delta T\cos(\omega t)$.

$$k = k_0\{1+\Delta_k\cos[\sigma(x-vt)]\}, \quad \text{Eqn 1a}$$

$$C = C_0\{1+\Delta_c\cos[\sigma(x-vt+\varphi)]\}. \quad \text{Eqn 1b}$$

$$\frac{\partial^2\bar{T}}{\partial x^2} = \frac{1}{\alpha}\frac{\partial\bar{T}}{\partial t} + \frac{1}{L}\frac{\partial\bar{T}}{\partial x} + \frac{1}{V}\frac{\partial^2\bar{T}}{\partial x\partial t}, \quad \text{Eqn 2a}$$

$$\bar{q} = -k^*\left(\frac{\partial\bar{T}}{\partial x} + \frac{1}{2V}\frac{\partial\bar{T}}{\partial t}\right). \quad \text{Eqn 2b}$$

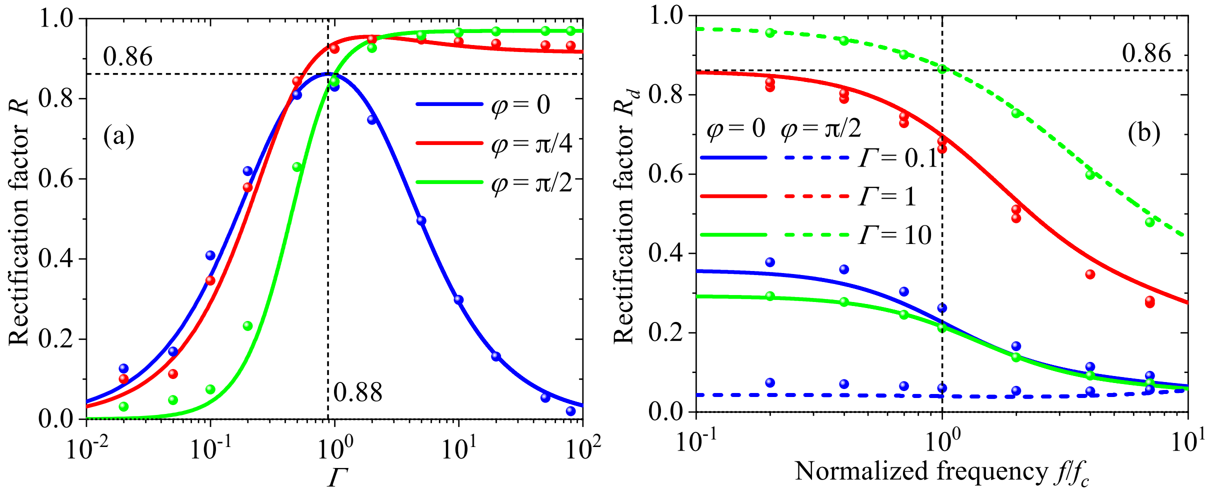


**Fig. 2.** Rectification factors for the heat fluxes carried by thermal waves at the (a) arrival and (b) departure positions, as functions of the normalized speed $\Gamma = v/\sigma\alpha_0$ and frequency, respectively. Points represent the numerical solution of the diffusion equation for the non-constant thermal properties in Eqns. (1a) and (1b).

## References

[1] J. Ordonez-Miranda, Y. Guo, J.J. Alvarado-Gil, S. Volz, M. Nomura, Thermal-Wave Diode, Phys. Rev. Applied 16 (2021) L041002. https://doi.org/10.1103/PhysRevApplied.16.L041002.

[2] I. Forero-Sandoval, J. Chan-Espinoza, J. Ordonez-Miranda, J. Alvarado-Gil, F. Dumas-Bouchiat, C. Champeaux, K. Joulain, Y. Ezzahri, J. Drevillon, C. Gomez-Heredia, J. Ramirez-Rincon, VO2 Substrate Effect on the Thermal Rectification of a Far-Field Radiative Diode, Phys. Rev. Appl. 14 (2020) 034023. https://doi.org/10.1103/PhysRevApplied.14.034023.