New solid-state thermal diode developed with better rectification performance

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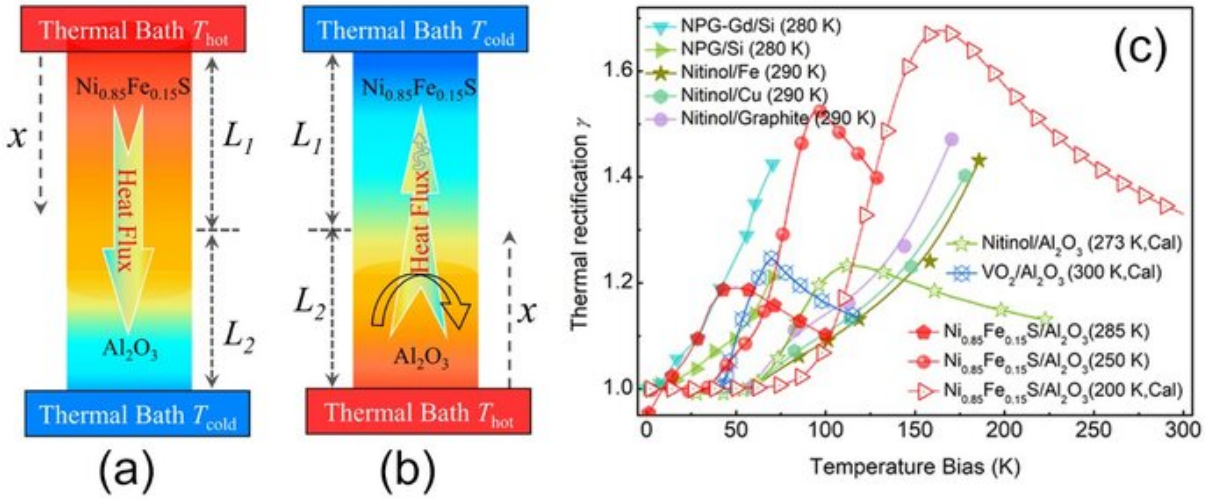

(a) and (b) represent for the schematic geometry of the thermal diode consisting of Ni0.85Fe0.15S and Al2O3 for forward and reverse direction. (c) Thermal rectification factor (γ) as a function of temperature bias (ΔT) along with those reported. Credit: Zhang Xuekai

The effective control of heat transfer is important in improving energy efficiency. The thermal diode is one of the key elements of heat flow

control. Like the current rectification effect found in electronic diodes, heat flow is easily maintained in one direction in a thermal diode, while it is obstructed in the opposite direction. Sizable heat rectification can be obtained using a junction of two solid materials with opposite trends in thermal conductivity as a function of temperature. This type of thermal diode offers scalability and a simple analogy of electrical diode design.

A team led by Prof. Tong Peng from the Hefei Institutes of Physical Science (HFIPS) of the Chinese Academy of Sciences (CAS) had reported that they've found sulfides $Ni_{1-x}Fe_xS$, a series of materials that may unlock new ways to create better thermal rectification.

Recently, the same team announced that they constructed a novel thermal diode with a combined material of $Ni_{0.85}Fe_{0.15}S$ and alumina, which displayed superior performance to any other solid-state thermal diodes ever reported. Their up-to-date result was published on Journal *Physical Review Applied*.

In their previous study, they discovered the abrupt jump of thermal conductivity in the vicinity of the first-order phase transition (FOPT) in $Ni_{1-x}Fe_xS$. The change of thermal conductivity is as high as 200%, which suggests the sulfides are promising materials for designing solid-state thermal diodes.

On this base, they constructed a thermal diode with $Ni_{0.85}Fe_{0.15}S$ (bonded by 10wt.%Ag) and Al_2O_3 as two segments. The thermal diode exhibits excellent thermal rectification performance. When the cold end of the thermal diode is set at 250 K, at a temperature bias of 97 K, the maximum thermal rectification coefficient γ_{max} reaches 1.51.

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The $Ni_{0.85}Fe_{0.15}S/Al_2O_3$ thermal diode shows advantages over other solid-state thermal diodes. Namely, its γ_{max} is the largest among the reported values, meanwhile the requested temperature bias for driving γ_{max} is at least 100 K less than that of reported thermal diodes having comparable γ_{max} values.

The outstanding thermal rectification effect of the current thermal diode may have potential applications in thermal management systems such as caloric refrigeration and energy conversion.

Moreover, on the base of systematical experimental and theoretical analysis, the team clarified how the thermal rectification factor is affected by the cold terminal temperature, the length ratio of $Ni_{0.85}Fe_{0.15}S$ and Al_2O_3 segments, and the sharpness of the FOPT of $Ni_{0.85}Fe_{0.15}S$.

These new results provide guides for designing new solid-state thermal diodes in the future.

More information: Xuekai Zhang et al, Large Thermal Rectification in a Solid-State Thermal Diode Constructed of Iron-Doped Nickel Sulfide and Alumina, *Physical Review Applied* (2021). DOI: 10.1103/PhysRevApplied.16.014031

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