Waste-heat Harvesting by Thermoelectric Generator Coupled with Hygroscopic Hydrogel in Energy Industry

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Supplementary Note S1

Energy conversion efficiency of the system

The overall energy conversion efficiency of the system (η_{system}) encompasses both the thermoelectric generator (TEG) conversion efficiency and the cooling effect of the hydrogel. The formula for calculating the TEG conversion efficiency is:

$$\eta_{system} = \frac{P_{out}}{Q_{in}}$$

where P_{out} represents the electrical power output of the TEG, and Q_{in} denotes the input power of the heating sheet, which can be 2W, 3W, or 4W, as these values correspond to the heat transferred to the TEG. Consequently, the integrated thermal management system proposed in this paper, utilizing a TEG of dimensions 40 mm x 40 mm (length x width), achieves energy conversion efficiency of 0.035%.

Supplementary Note S2

Repeated tests and infrared imaging

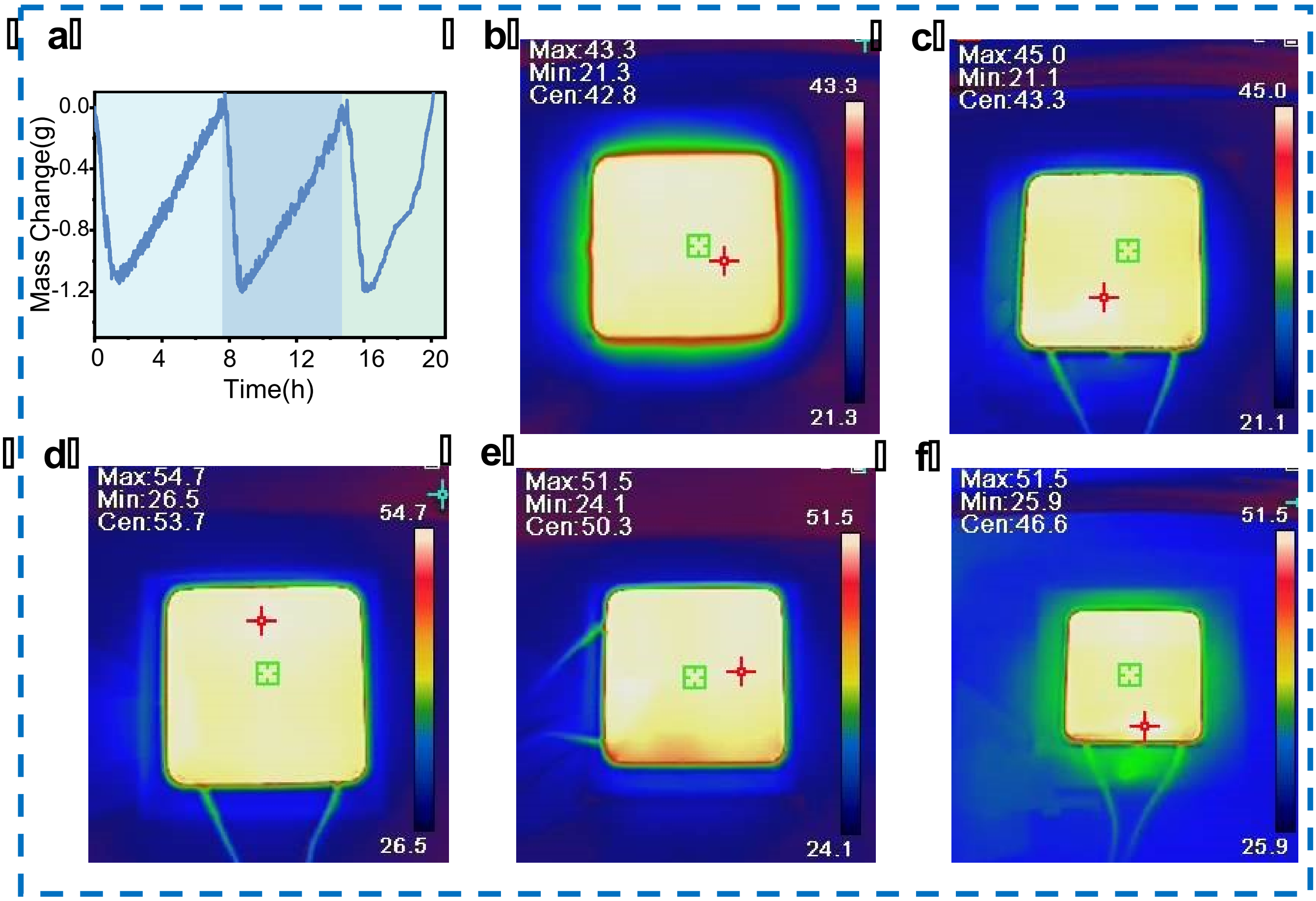

Fig.S1. The long-term stability of the hydrogel over multiple cycles and the infrared surface images. (a) Mass change of hygroscopic hydrogel during three cycles. (b)-(d) When the thickness of hydrogel is set as 5 mm, the surface temperature of TEGHT at different power inputs for the heat source. (c)(e)-(f) Under the input power of 3 W for the heat source, the surface temperature of the integrated system with different hydrogel thickness.

Supplementary Note S3

The integrated thermal management system designed for industrial application features an integrated and tilt-mountable fixed device.

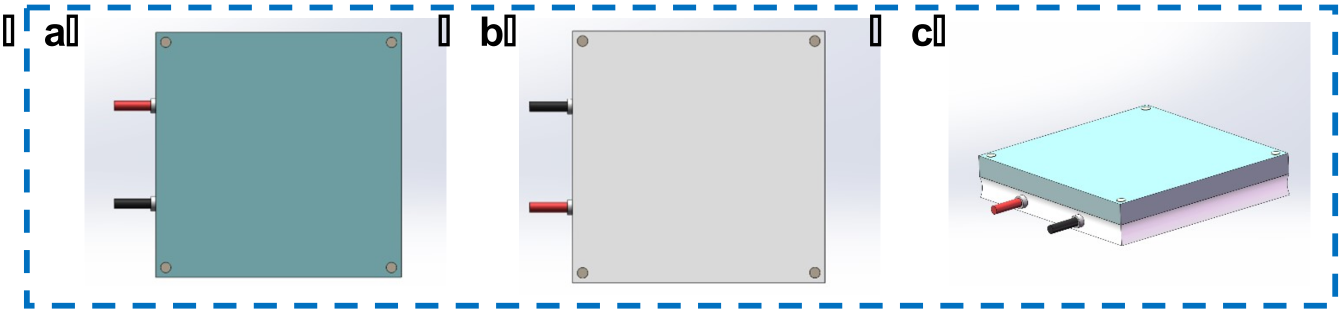

Fig.S2. (a)Top view of the device. (b)Bottom view of the device. (c) Overall view of the device.

Hydrogels exhibit sustained structural integrity over extended periods of use, such as a duration of seven days.

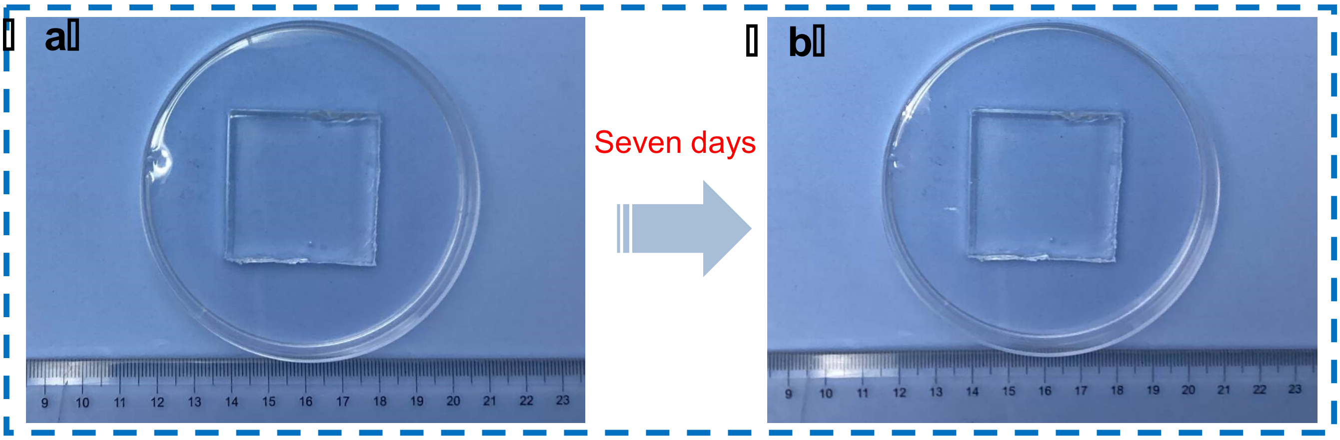

Fig.S3. (a) Newly prepared hydrogel. (b) Hydrogel after a period of use.

Supplementary Note S4

The specific comparisons with existing thermal management systems in terms of cost, scalability, and performance are shown in Table S1.

Table S1 Cost, Scalability, and Performance Comparison

Thermal Management System Type	**Performance Indicators**	**Cost**	**Scalability**
1D/2D Liquid Crystal Thermal Conductivity Network[1]	Reduces mobile CPU temperature by 3.4 °C	Relatively high cost	Suitable for thermal management and waste heat recovery of electronic devices
Anisotropic Graphene Film[2]	In-plane thermal conductivity of 81.2 W/mK, through-plane thermal conductivity of 5.1 W/mK	Relatively high cost	Mechanical flexibility, suitable for devices of irregular shapes
Millefeuille-Inspired PVA/BNNS Nanocomposites[3]	In-plane thermal conductivity of 21.4 W/(m·K) (22.2 volume% BNNS addition)	Relatively low cost	Scalable manufacturing methods, suitable for next-generation thermal management systems
Hygroscopic Composite Backplate[4]	Reduces the daily average temperature of photovoltaics by 1.5 to 6.4 °C	Low cost, low raw material cost	Flexible application for newly built or installed photovoltaic panels
TEG Coupled Hydrogel Integrated Thermal Management (This work)	Reduces the surface temperature of the heat source by 32 °C, output voltage of 0.20 V (3 W input power)	Low cost, environmentally friendly	Simple structure, flexible packaging, suitable for a variety of devices

Supplementary Note S5

Looking Forward

To extend the applicability to industrial uses, enhance energy conversion efficiency, and achieve integration for improved system performance, future research can build upon the hygroscopic hydrogels presented in this study to develop materials with superior water absorption and retention capabilities. This advancement would further augment thermal management efficiency. Additionally, the development of novel environmentally responsive materials that can adapt to the diverse demands of industry is essential. Moreover, thermal interface materials (TIMs) play a pivotal role between heat sources and TEGs. In this study, a 0.5-millimeter-thick conductive silicone grease film was utilized. Future research could focus on the development of TIMs with higher thermal conductivity and improved thermal stability, which would reduce thermal contact resistance and enhance heat transfer efficiency, thereby facilitating their application in industrial settings.

Reference

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