Supporting information

Adaptive Radiative Cooling and Thermal Insulation Enabled by Thermoresponsive Cholesteric Liquid Crystal Aerogels

Yanjun Liang[a], Xiaoyu Zhang[a], Jian Wang [a], Xinqi Liu[a], Nannan Liu[a], Jian Zhang[a], Xiao Huang[a]**

[a] Institute of Advanced Materials (IAM), School of Flexible Electronics (SoFE), Jiangsu National Synergetic Innovation Center for Advanced Materials (SICAM), Nanjing Tech University (Nanjing Tech), Nanjing 211816, China.

Corresponding authors: iamjzhang@njtech.edu.cn (J. Zhang), iamxhuang@njtech.edu.cn (X. Huang).

Supplementary Figures

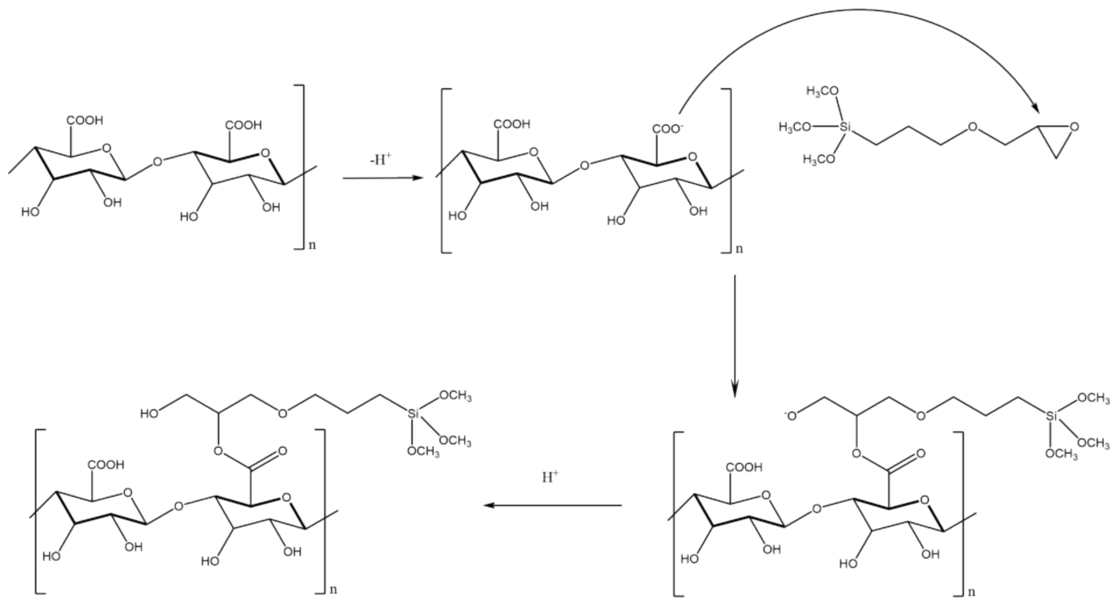

Fig. S1. The formation process of the cellulose aerogel network framework.

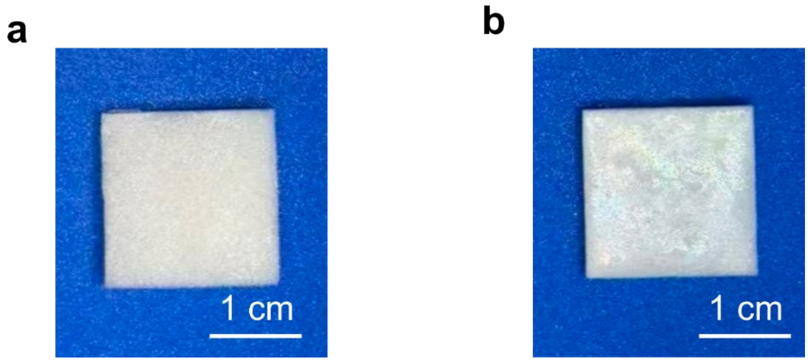

Fig. S2. Photographs of (a) aerogel and (b) TRCA.

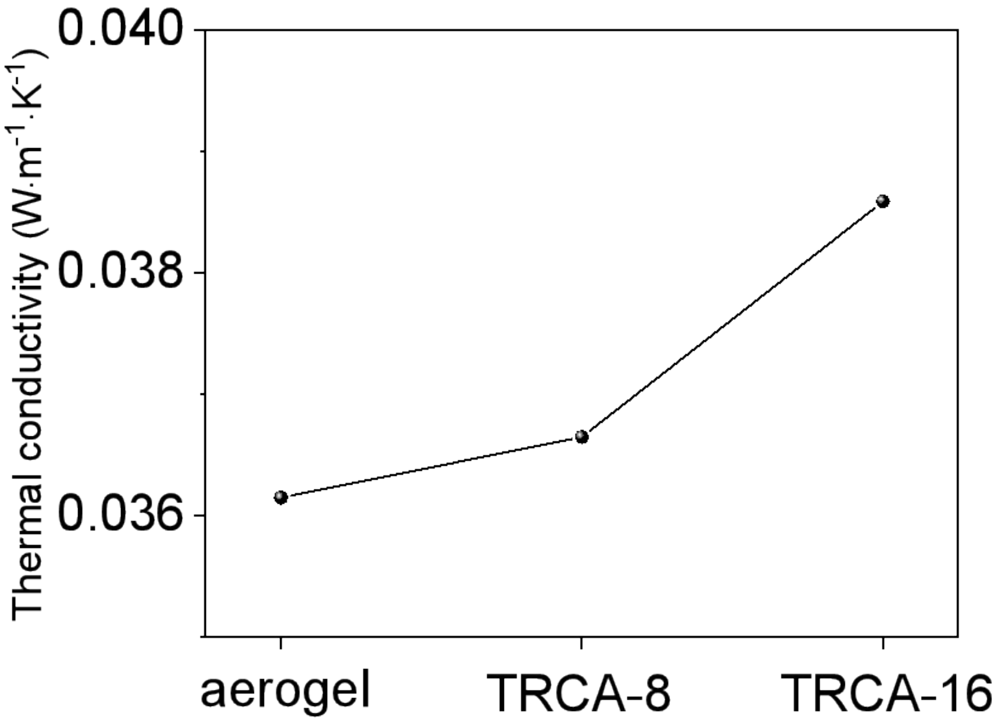

Fig. S3 Thermal conductivity of bare aerogel, TRCA-8 and TRCA-16.

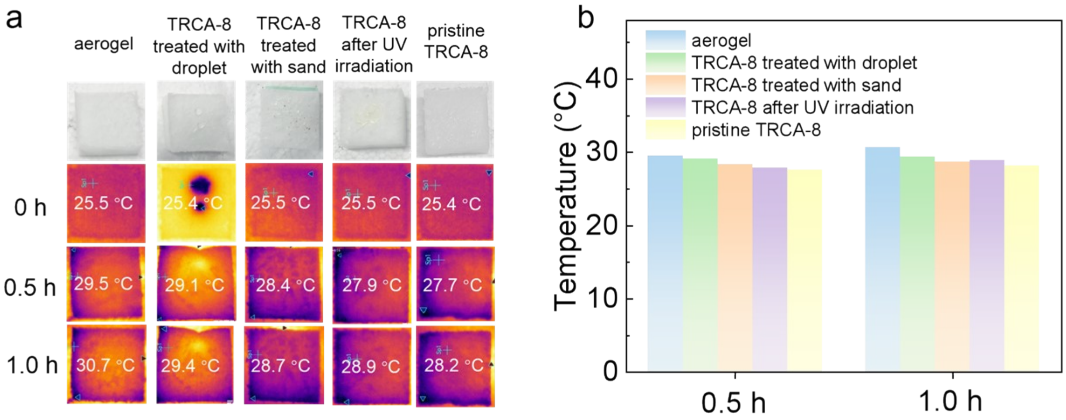

Fig. S4. (a) Time-resolved infrared images of aerogel, TRCA-8 treated with droplet, TRCA-8 treated with sand, TRCA-8 after UV irradiation and pristine TRCA-8, under xenon-lamp irradiation at 0.8 sun intensity (800 W·m^{-2}). (b) Corresponding surface temperature values of the five samples as a function of irradiation time.

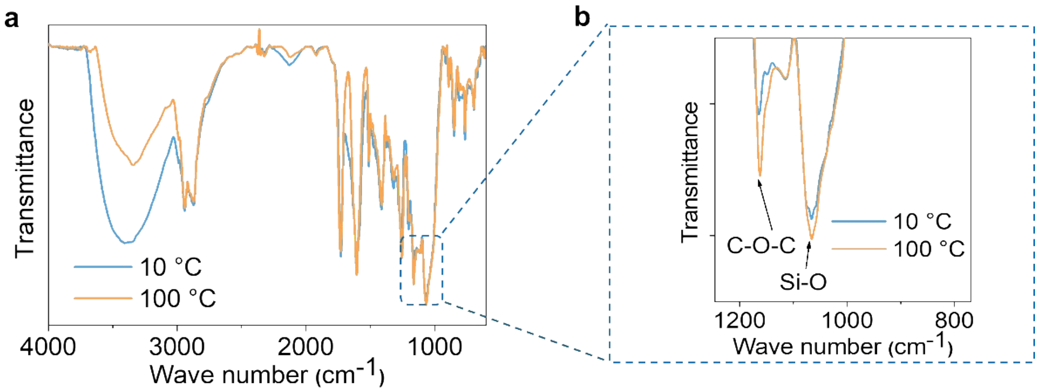

Fig. S5. (a) FTIR spectra of TRCA under different temperatures. (b) Enlarged view of (a) within the atmospheric window band (1250-769 cm^{-1}).

Table S1. Comparison of adaptive radiative cooling performances between recently reported materials and the materials developed in this work.

Material	Emissivity	Adaptive performance driving signal	Daytime cooling ΔT (°C)	Nocturnal overcooling resistance	Ref.
PE/POM/ TIPN	94.1%	Temperature	5.3°C(under solar irradiation ≈800 W·m^{-2})	YES	1
MXene/ PVDF	96.1%	Flipping the film	9.8°C(under solar irradiation ≈500 W·m^{-2})	YES	2
Cellulose/ PCM	90.2%	Temperature	9.2°C in summer and 11.5°C in winter	YES	3
PDMS/BN/ ODE	93%	Temperature	17.3°C(under solar irradiation ≈1000 W·m^{-2})	YES	4
PE/ePtFE/ PEG800	75%	Temperature	9.0°C(under solar irradiation ≈880 W·m^{-2})	YES	5
P(VdF-HFP)/ ETA	99%	Humidity	5.8°C(under solar irradiation ≈1245 W·m^{-2})	NO	6

Cellulose/ CLC	**98%**	**Temperature**	**8.5°C(under solar irradiation ≈575 W·m^{-2})**	**YES**	**This work**

Net cooling power calculation

The net cooling power was calculated according to the thermal equilibrium equation:

$$P_{net}(T_s) = P_{rad}(T_s) - P_{atm}(T_{amb}) - P_{sun} - P_{non-radiative} \#(1)$$

where $P_{net}(T_s)$ denotes the net cooling power of the material at surface temperature T_s, $P_{rad}(T_s)$ is the thermal radiative power emitted by the material itself, $P_{atm}(T_{amb})$ represents the power from atmospheric radiation, P_{sun} is the heating power induced by solar irradiation, $P_{non-radiative}$ refers to the non-radiative heat transfer power.

The radiative power of the material is derived by double integration over wavelength and angle, based on Planck's law of blackbody radiation and combined with the spectral emissivity of the material:

$$P_{rad}(T_s) = \int_0^{\frac{\pi}{2}} \int_{\lambda_{min}}^{\lambda_{max}} u_{bs}(\lambda, T_s) \cdot \epsilon(\lambda) \cdot d\lambda \cdot 2\pi \sin(\theta) \cos(\theta) d\theta \#(2)$$

where the spectral blackbody radiative power density $u_{bs}(\lambda, T_s)$ is defined as:

$$u_{bs}(\lambda, T) = \frac{2\pi hc^2}{\lambda^5} \cdot \frac{1}{e^{\frac{hc}{\lambda k_B T}} - 1} \#(3)$$

Here, h is Planck's constant (6.626×10^{-34} J·s), c is the speed of light (3×10^{8} m·s^{-1}), and k_B is Boltzmann's constant (1.38×10^{-23} J·K^{-1}), $\epsilon(\lambda)$ is the spectral emissivity of the material, measured experimentally by Fourier-transform infrared spectroscopy (FTIR) in the range of 2.5 to 25 μm. The wavelength integration ranges from 0.3 to 25 μm, covering both the solar spectrum and the atmospheric window, while the angular integration spans 0 to $\frac{\pi}{2}$, corresponding to hemispherical omnidirectional radiation.

The calculation of atmospheric radiative power follows the same principle as that of material radiation, with the temperature set to the ambient temperature T_{amb} and the atmospheric spectral emissivity $\epsilon(\lambda)$ introduced:

$$P_{atm}(T_{amb}) = \int_0^{\frac{\pi}{2}} \int_{\lambda_{min}}^{\lambda_{max}} u_{bs}(\lambda, T_{amb}) \cdot \epsilon(\lambda) \cdot \epsilon_{atm}(\lambda) \cdot d\lambda \cdot 2\pi \sin(\theta) \cos(\theta) d\theta \#(4)$$

$\epsilon_{atm}(\lambda)$ is calculated using the MODTRAN atmospheric radiative transfer model under the mid-latitude summer standard atmospheric profile and clear-sky conditions, consistent with the field measurement environment.

The weighted average reflectance R_{sol} of the material in the solar band is computed as:

$$R_{sol} = \frac{\int_{\lambda_{sol}} R(\lambda) S(\lambda) d\lambda}{\int_{\lambda_{sol}} S(\lambda) d\lambda} \#(5)$$

where $R(\lambda)$ is the spectral reflectance of the material, $S(\lambda)$ is the spectral irradiance of the standard AM1.5G solar spectrum, Δλ denotes the wavelength step. The solar absorptivity is given by $\alpha_s = 1 - R_{sol}$, and the solar irradiation heating power is expressed as:

$$P_{sun} = \alpha_s \cdot S_{solar} \#(6)$$

where S_{solar} is set to 600 W·m^{-2}.

Non-radiative heat transfer is dominated by convective heat transfer, obeying Newton's law of cooling:

$$P_{non-radiative} = h_c \cdot (T_{amb} - T_s) \#(7)$$

where h_c is the convective heat transfer coefficient, set to 0, 3, 6, 9, 12 W·m^{-2}·K^{-1}, T_{amb} is the ambient temperature (298 K), and T_s is the material surface temperature (288-308 K).

References

1 J. Liu, X. Yan, W. Wu, B. Ji, Y. Zhong, L. Zhang, B. Wang, X. Feng, H. Xu and Z. Mao, *Adv. Mater.*, 2025, **38**, e11445.
2 M. Shi, Z. Song, J. Ni, X. Du, Y. Cao, Y. Yang, W. Wang and J. Wang, *ACS Nano*, 2023, **17**, 2029-2038.
3 X. Lin, H. Wang, Y. Wu and S. He, *ACS Nano*, 2025, **19**, 25986-25998.
4 W. Jiang, T. Zhu, J. Chen, Q. Liu, Y. Liu, Z. Huang, X. Qi and Y. Wang, *Chem. Eng. J.*, 2024, **502**, 157862.
5 M. Yang, H. Zhong, T. Li, B. Wu, Z. Wang and D. Sun, *ACS Nano*, 2023, **17**, 1693-1700.
6 J. He, Y. Chen, R. Guo and S. Tang, *ACS Nano*, 2025, **19**, 30361-30370.