ANISOTROPIC COMPOSITE AEROGELS FOR SOLAR VAPOR GENERATION

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Outline

- Background and motivation
- Concept of rational design for anisotropic nanocomposites
- Design of anisotropic MXene aerogels for solar vapor generation
- Conclusions

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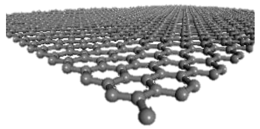
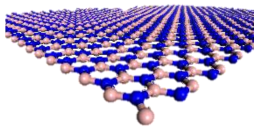
Nanocomposites: emerging materials for thermal energy regulation

Two-dimensional (2D) nanofillers

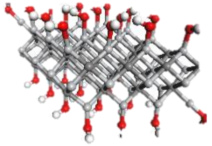
Graphene



Boron nitride

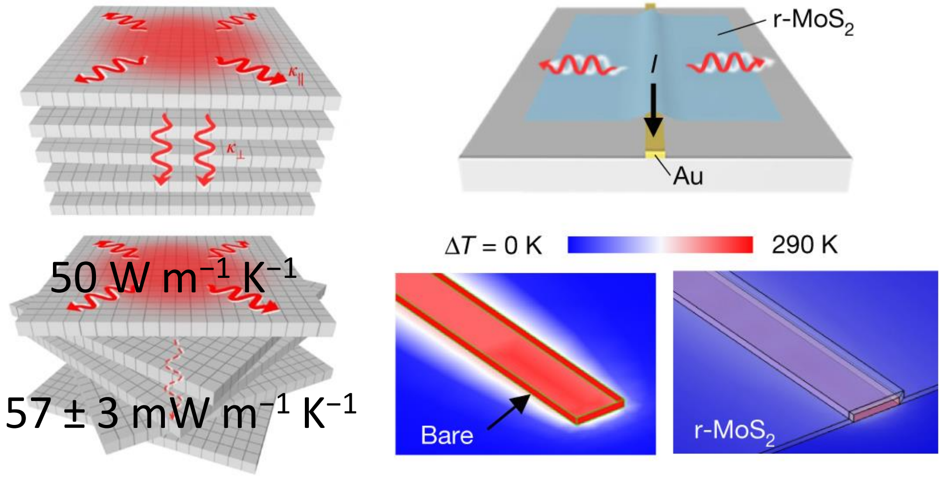


MXene



- One/few atomic layer
- Large lateral size
- High aspect ratio
- Large surface area

Anisotropic thermal conduction

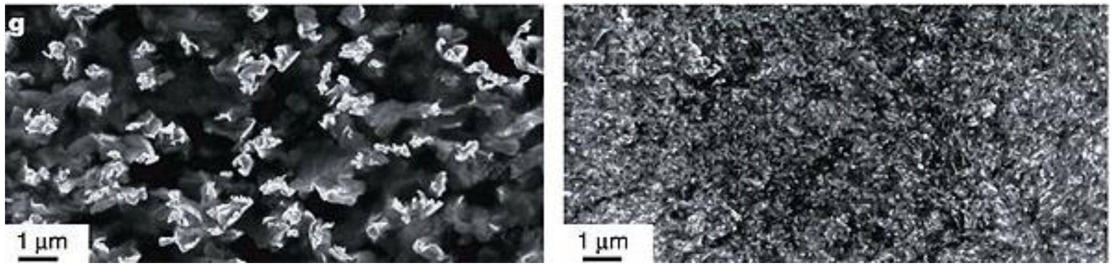


Kim et al. *Nature* **597**, 660–665 (2021)

Conventional processing technique

Dispersion → Mixing → Forming

Randomly dispersed nanofillers in matrix



Stankovich et al. *Nature* **442**, 282-286 (2006)

How to rationally translate the anisotropic properties to bulk composites?

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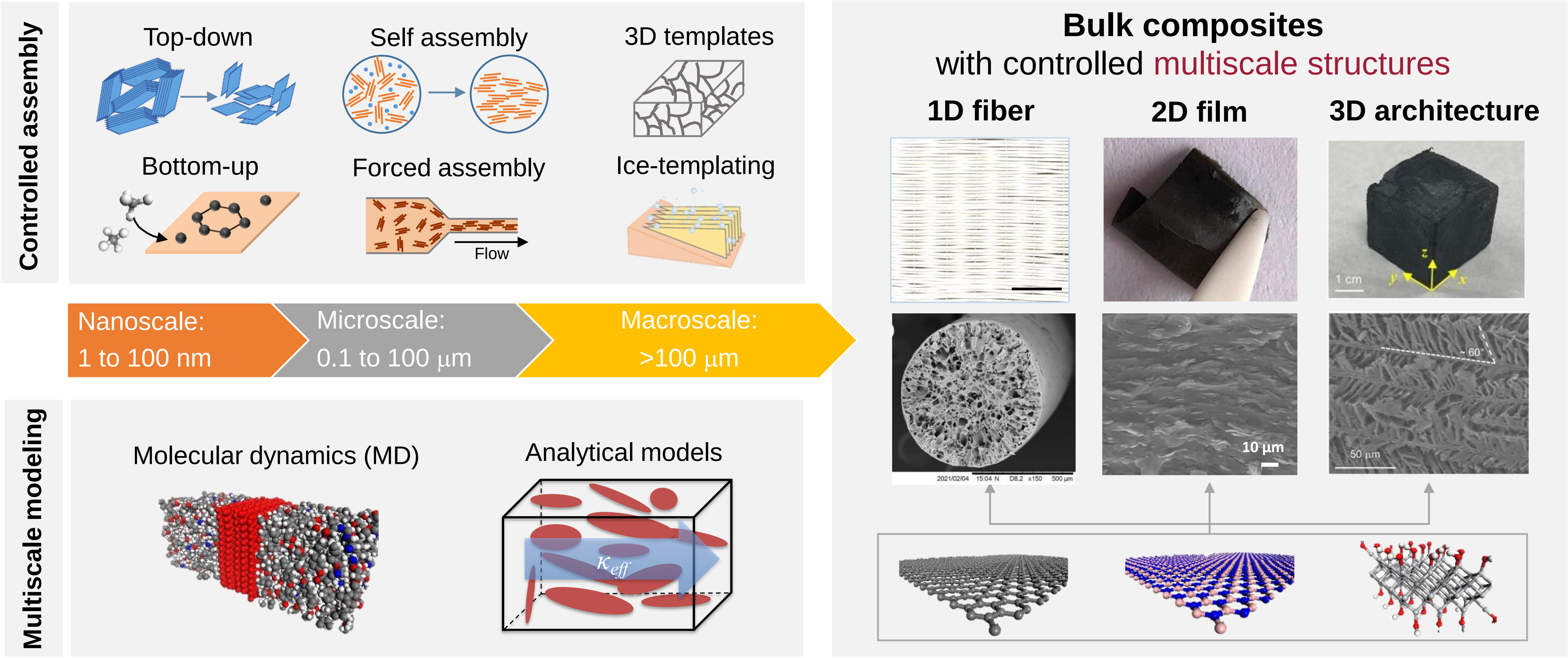
Rational design through multiscale modeling and controlled assembly



Shen, Zheng, Kim. *Progress in Materials Science*, 2021, 115, 100708.

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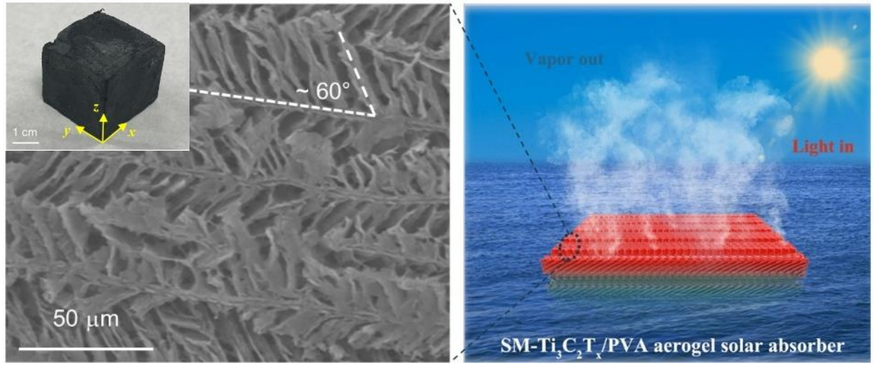
Tailored multifunctionalities for thermal management

Solar absorption

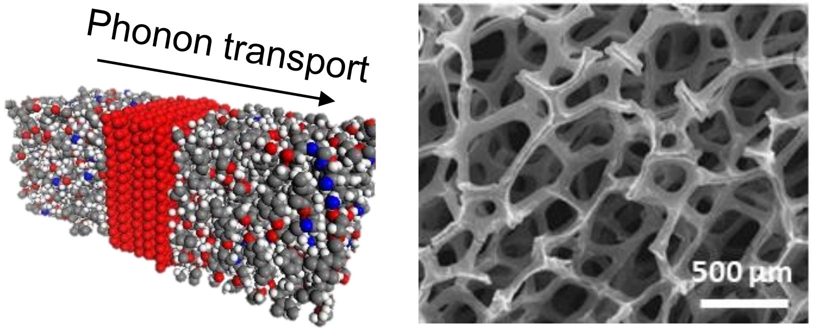
Electrical conductivity

MXene aerogels for solar-thermal heating



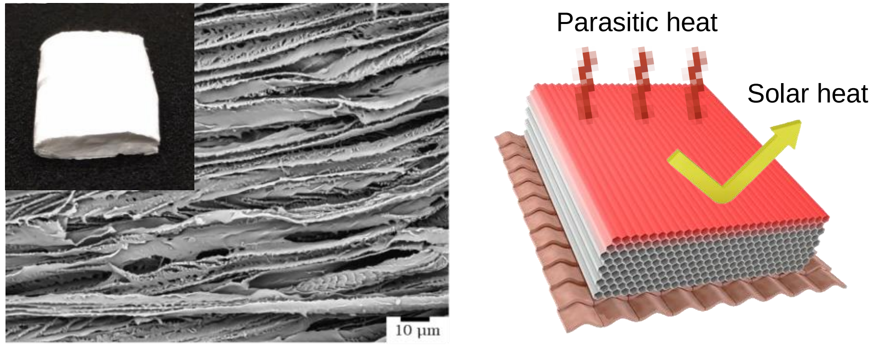
Advanced Functional Materials, 2022

Graphene/polymer composites for Thermal interfaces



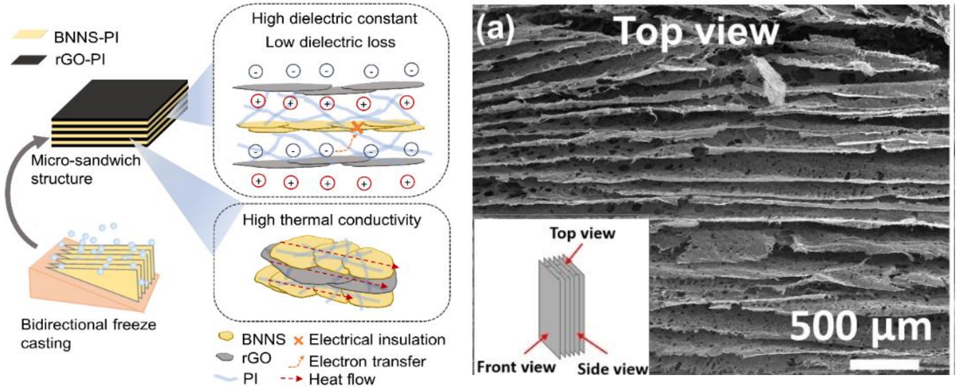
Nano lett 2016; ***Mater. Horizons*** 2018

BNNS aerogels for energy-efficient cooling



Nature communications 2022; ***Nano-micro letters*** 2022

Boron nitride/graphene films for dielectrics



Adv. Funct. Mater. 2020

Thermal conductivity

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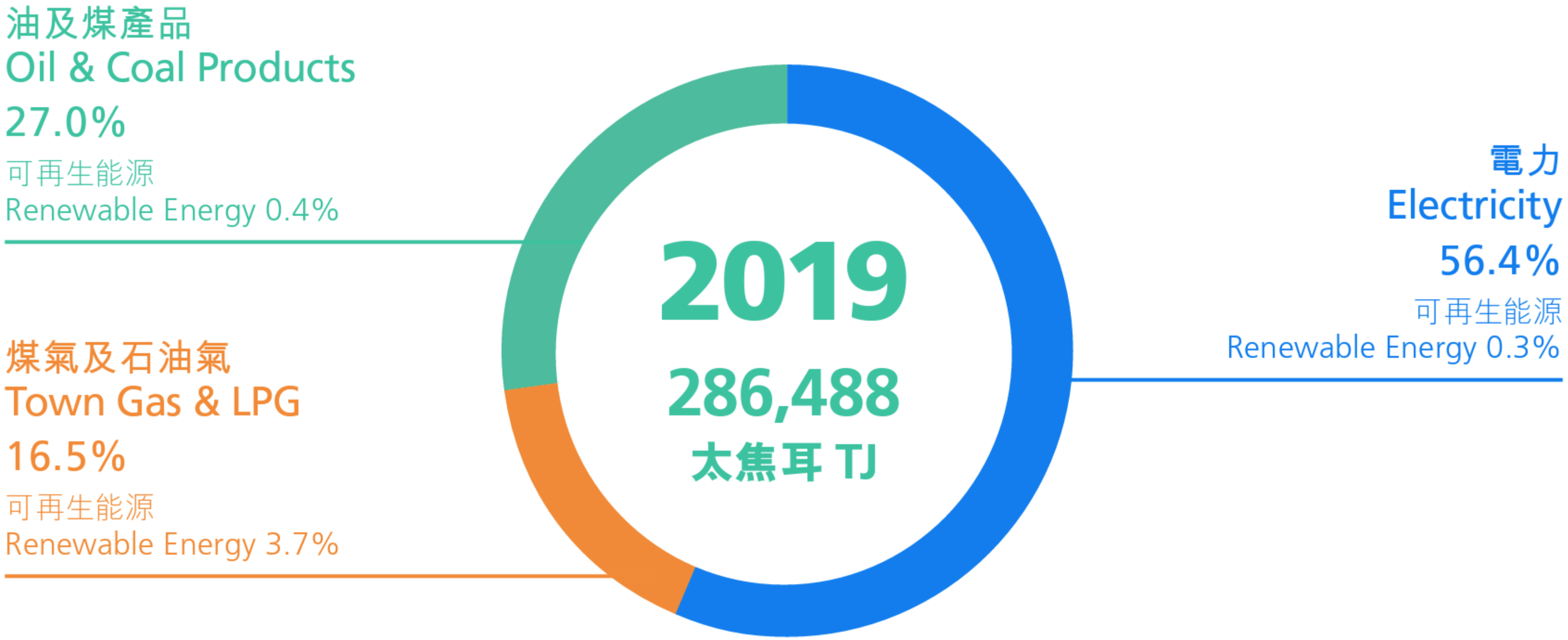
MXene aerogels for solar vapor generation

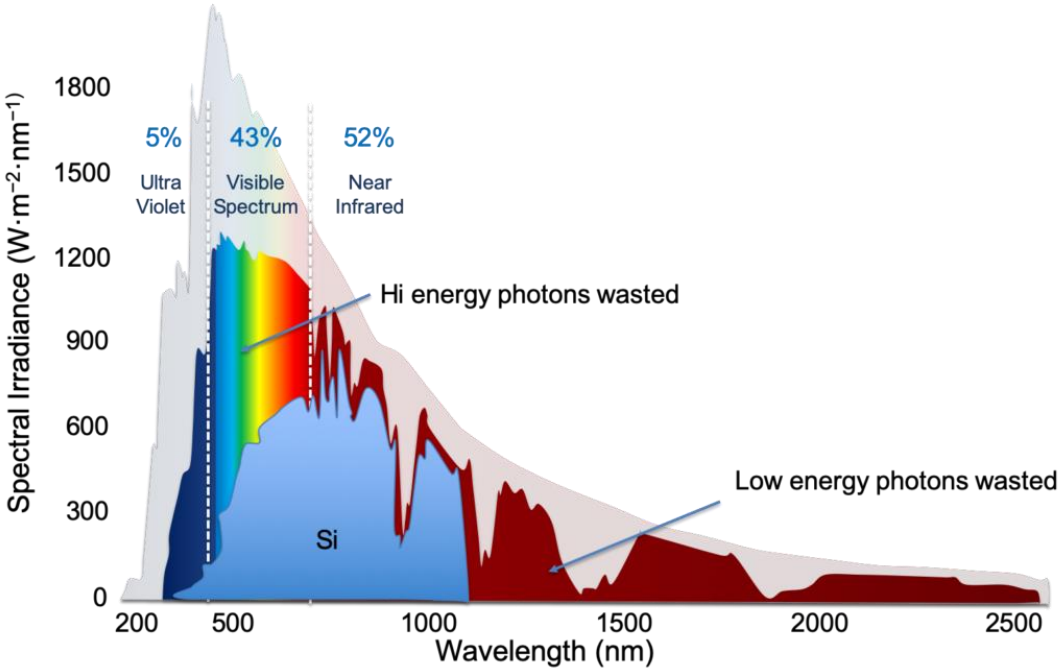
- Renewable electricity accounts for only 0.3% of the "Electricity" generation
- Includes solar energy used to generate electricity by PV panels
- Solar energy is abundant but has not been fully utilized



*Hong Kong Energy End-Use Data 2021, EMSD of HKSAR

Solar energy conversion

- Photovoltaic (PV)
  - Utilize partial solar spectrum
  - Low conversion efficiency
- **Solar-thermal**
  - Utilize full solar spectrum
  - High conversion efficiency



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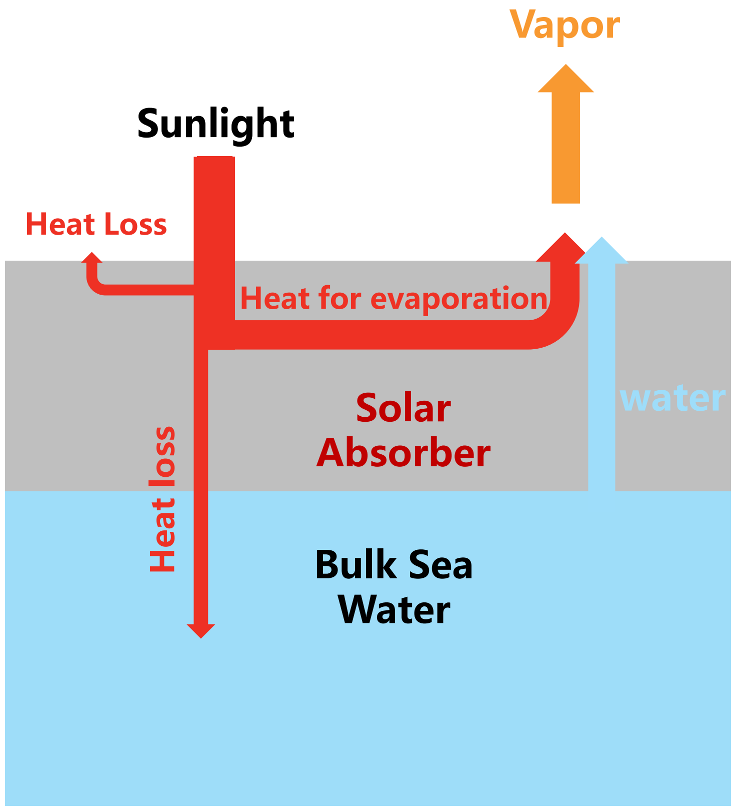
Solar-powered water evaporation

- Highly efficient utilization of solar heat for clean water generation by concentrating the heat at the water/air interface using solar absorber



To achieve a high energy efficiency for solar absorber

(i) a high optical absorption in the solar wavelengths of 0.3 to 2.5 µm to maximize the solar-to-thermal conversion

(ii) an excellent thermal management to minimize the heat loss

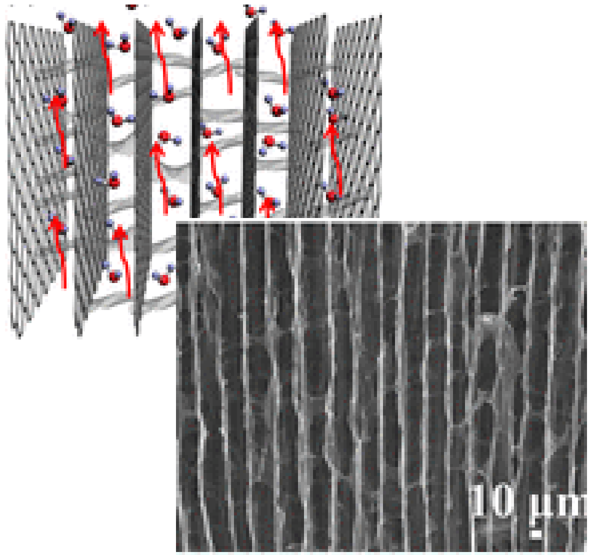
(iii) a proper water management to ensure sufficient water supply to the evaporation surface

Conventional solar absorber design

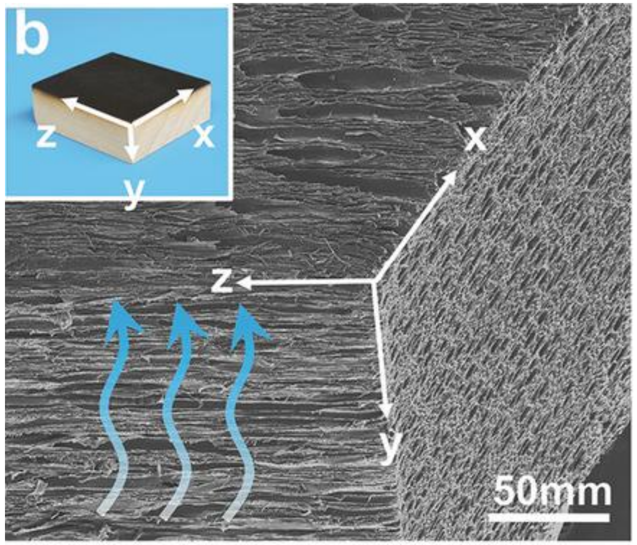
- 3D porous structure made from photothermal materials, e.g., carbon nanomaterials, plasmonic nanoparticles, MXene, etc.

Vertical pores

- Fast water transport
- Significant heat loss to bulk water



Zhang et al. *ACS Nano* 2017, 11, 5087−5093



Liu et al. *Adv. Energy Mater.* 2018, 8, 1701616.

Horizontal pores

- Good thermal insulation
- Slow water transport

Simultaneously achieving fast water transport and mitigated heat loss for high energy efficiencies is highly challenging.

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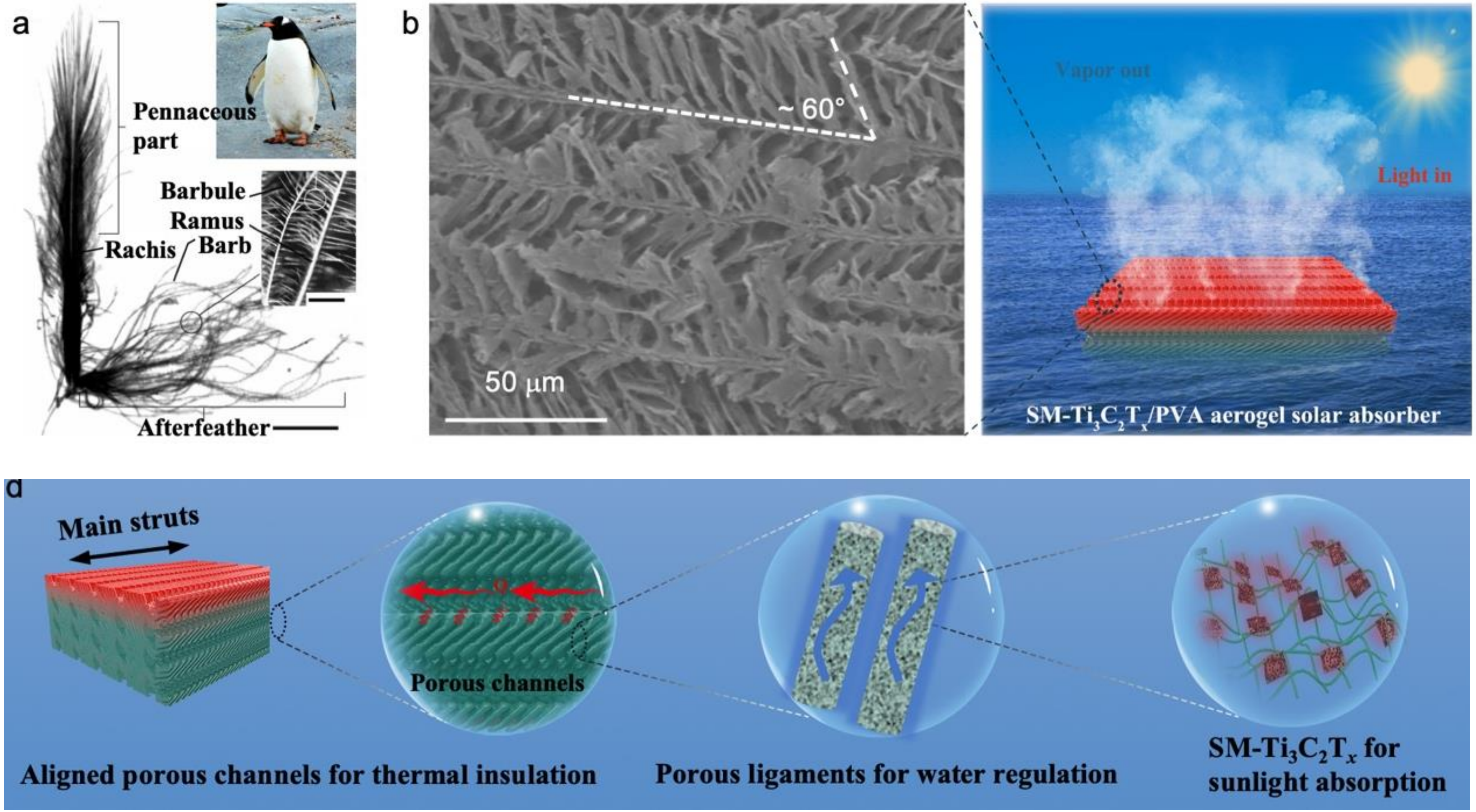
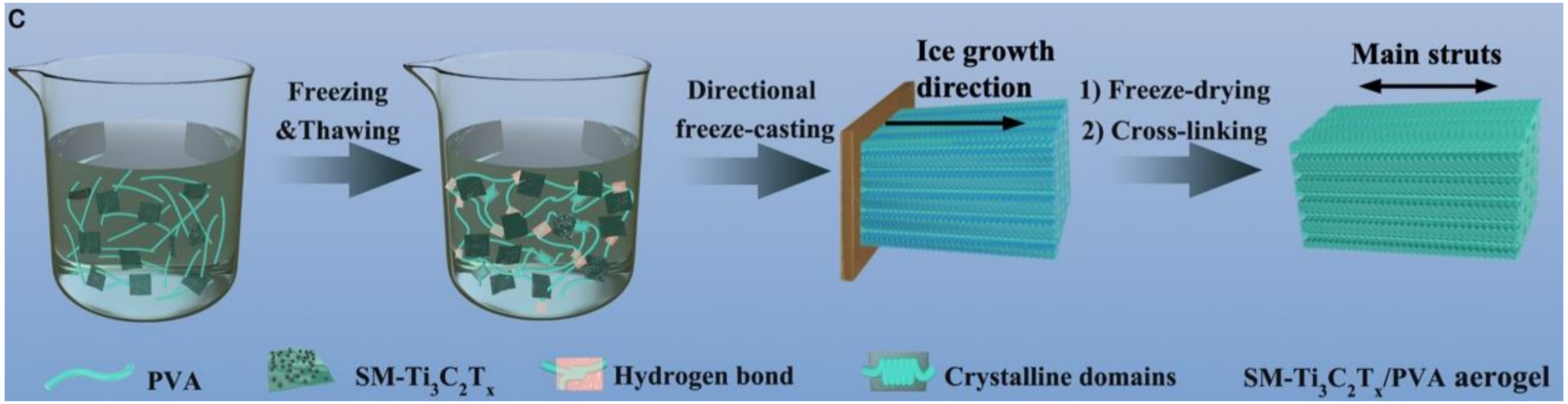
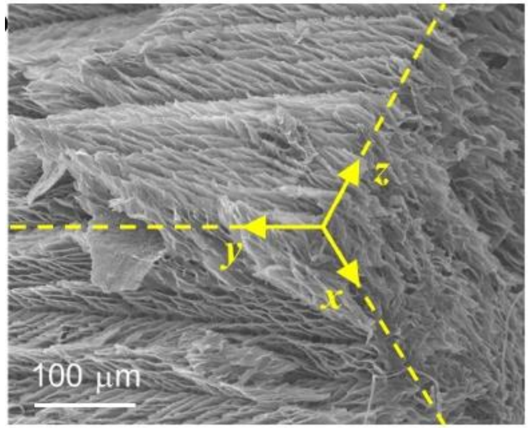
Biomimetic MXene/PVA aerogel for solar-powered evaporation

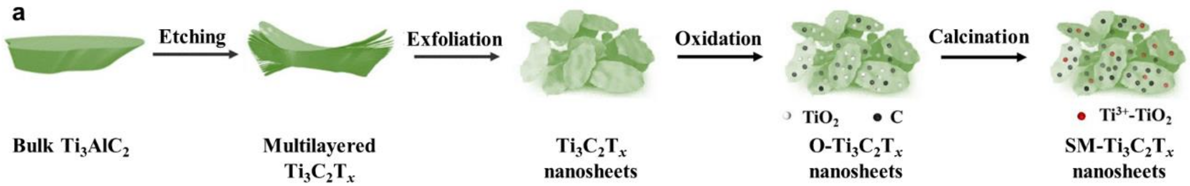


Zhang, Shen*, Kim*, et al. *Adv. Funct. Mater.* 2022, 32, 2111794.

Fabrication of MXene/PVA aerogel by directional freeze-casting

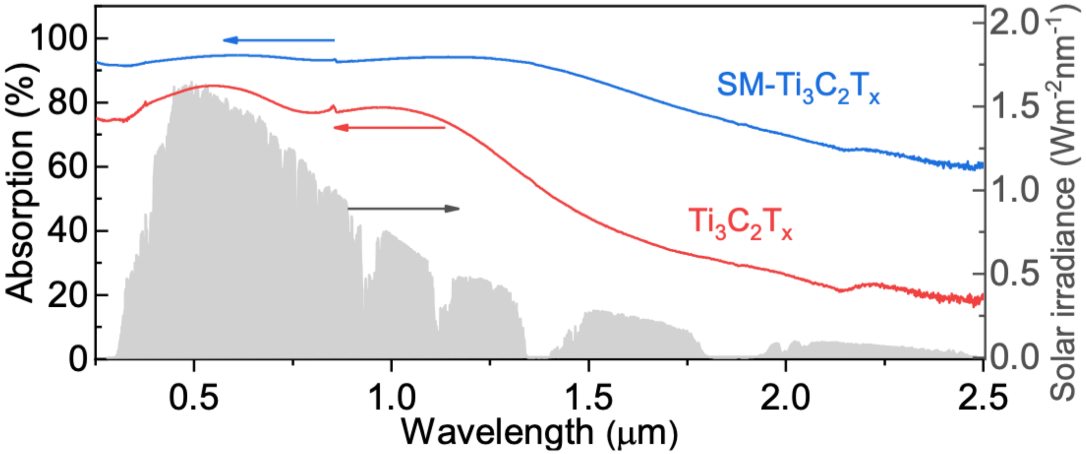




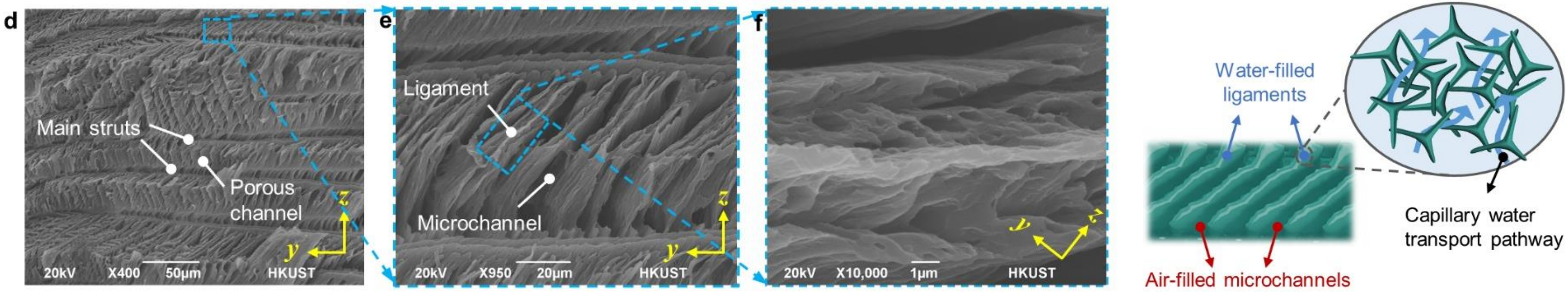


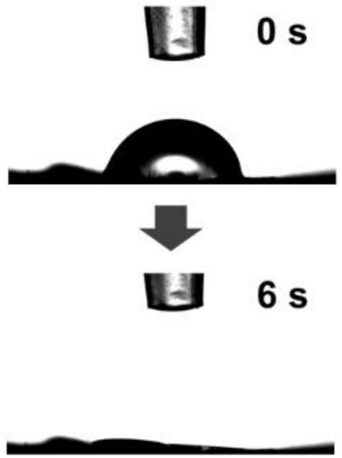
Spectrally modified $Ti_3C_2T_x$ (SM-$Ti_3C_2T_x$) MXene

- MXene: low emissivity for low heat loss
- Introduce Ti^{3+} and TiO_2 on the surface of MXene
- Improved absorption in solar spectrum



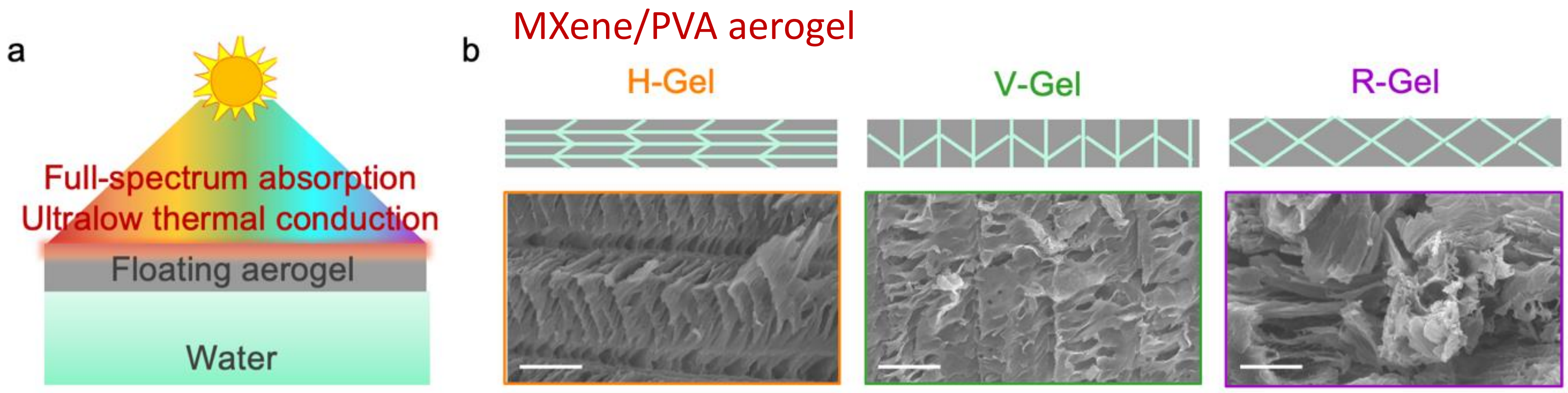
Hierarchical porous structures of MXene/PVA aerogel

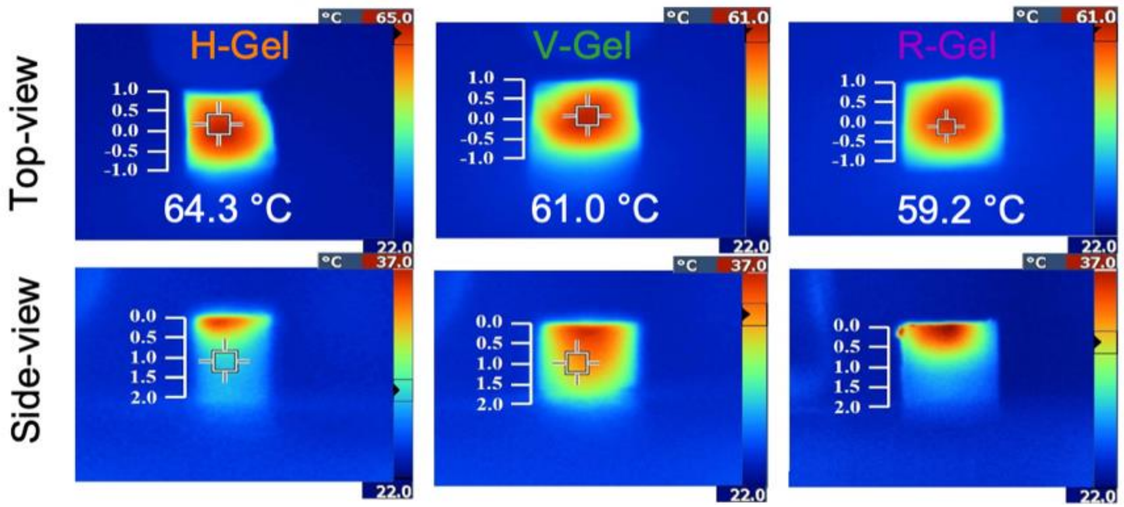




- Horizontal porous channels (~50 µm) sandwiched between main struts -> excellent thermal insulation
- Abundant ligaments formed at an angle of ~ 60°, further dividing the porous channels into microchannels of 10 to 20 µm in the transverse direction -> self-floating
- Smaller pores of less than 1 µm inside hydrophilic ligaments -> fast capillary water transport

Thermal management of MXene/PVA aerogel

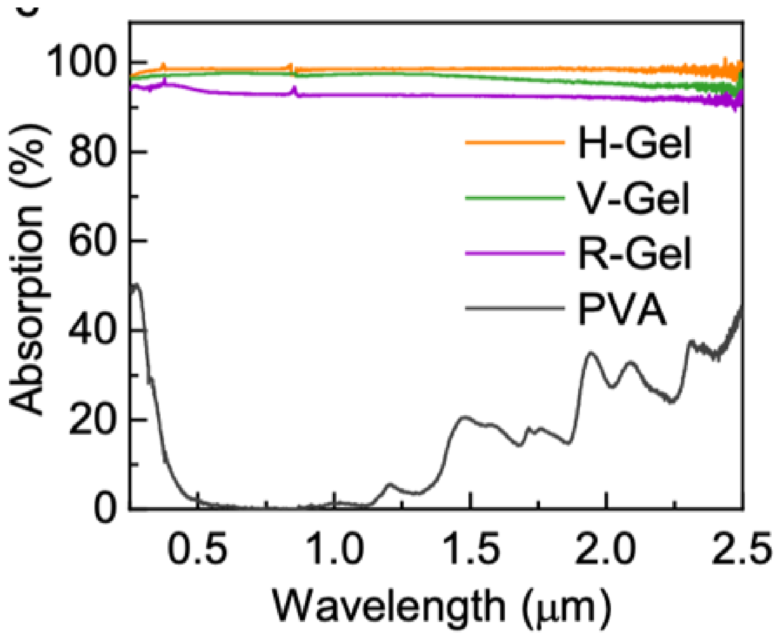


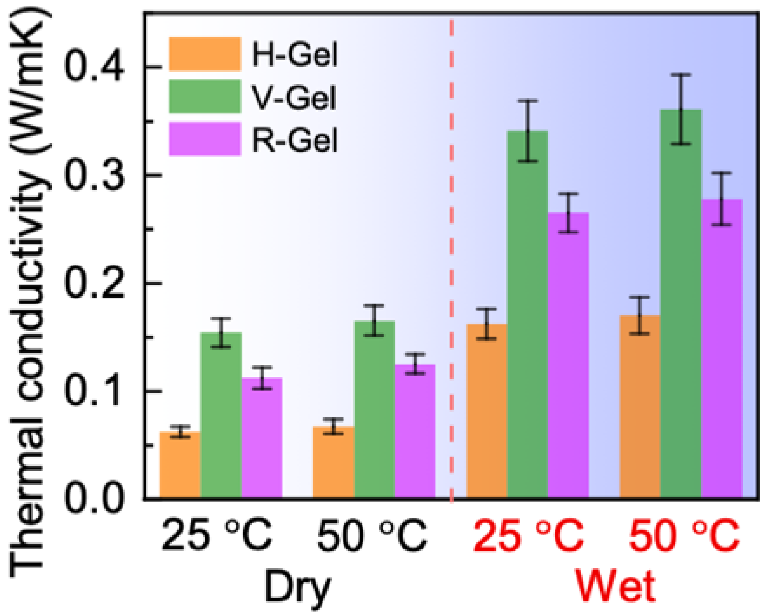


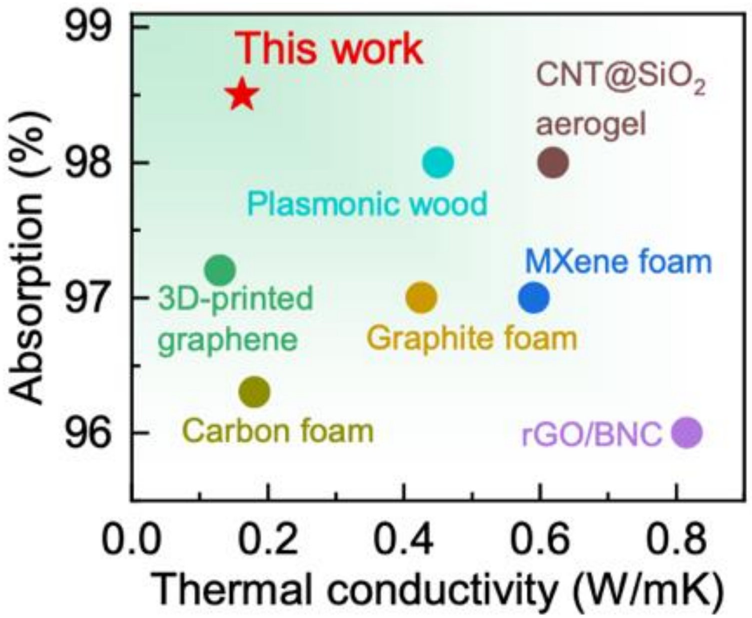
MXene/PVA aerogel with horizontal pore channels (H-Gel)

- Higher surface temperature
- Less heat loss in the thickness direction
- Better overall thermal management capability

Thermal conductivity and solar absorption of MXene/PVA aerogel



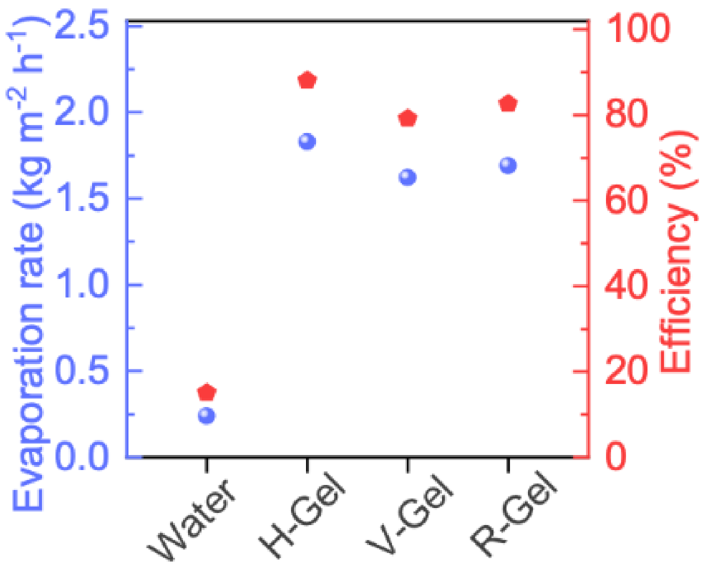


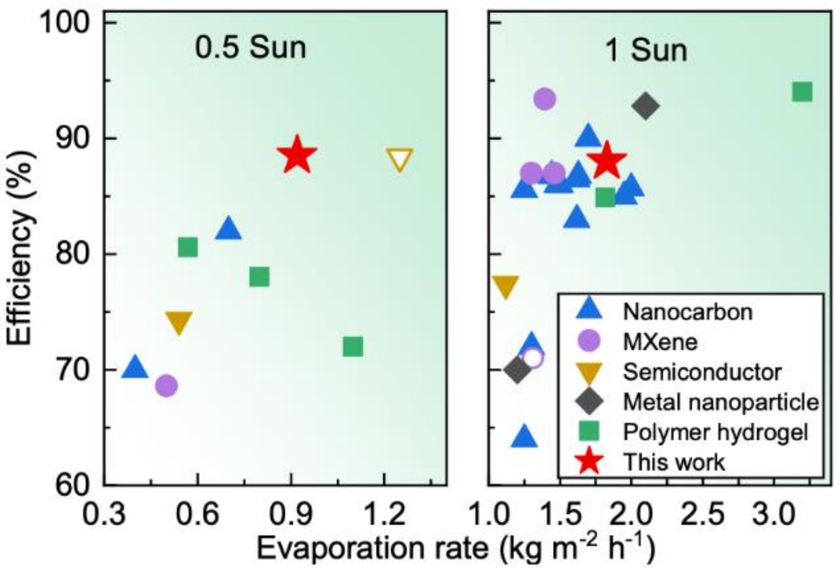


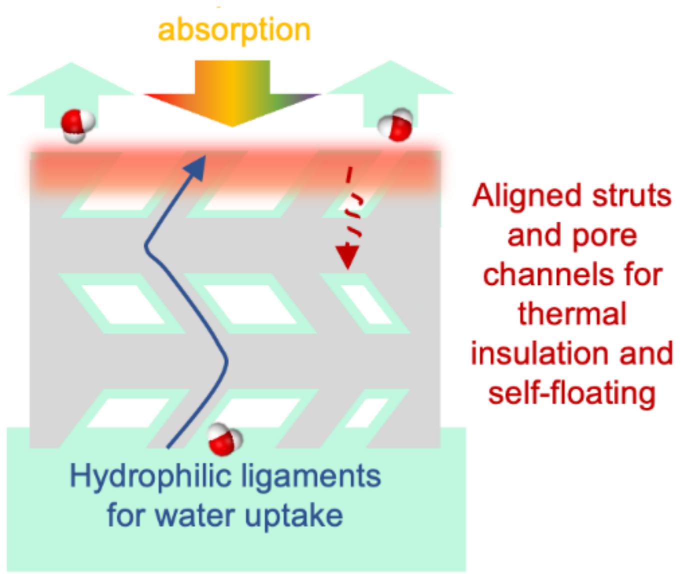
MXene/PVA aerogel with horizontal pore channels (H-Gel)

- 98.5% absorption of solar energy
- Low thermal conductivity of 0.162 $Wm^{-1}K^{-1}$ even at wet state
- Best combined properties among different solar absorbers

Evaporation rate and energy efficiency of MXene/PVA aerogel



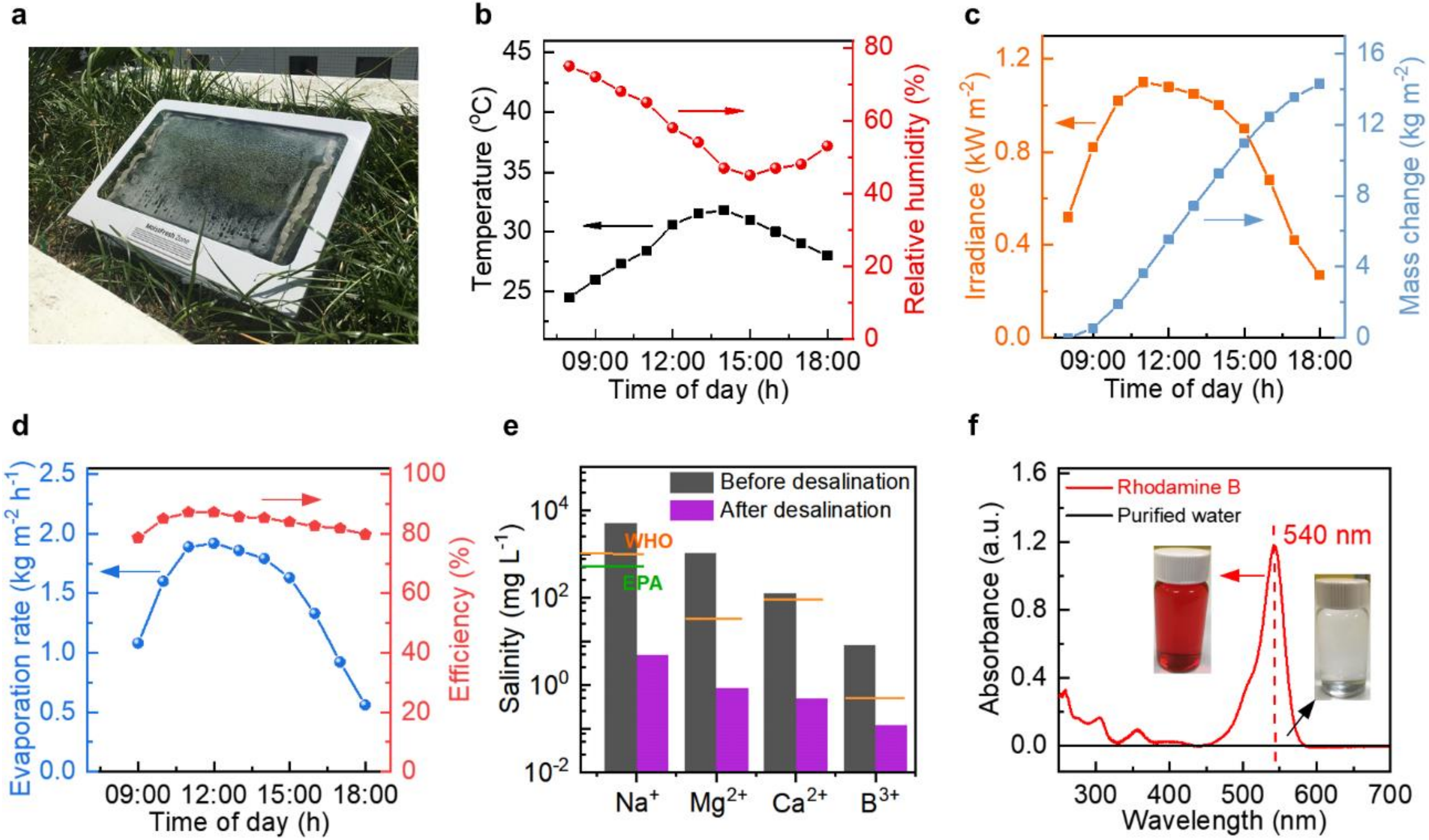




MXene/PVA aerogel with horizontal pore channels (H-Gel)

- Energy efficiency of 88 %: higher than V-Gel and R-Gel (~80%)
- Evaporation rate of 1.83 kg m^{-2} h^{-1}: 7.9 times that of neat water
- Excellent energy efficiency and evaporation rate even under weak solar irradiation

Practical water desalination under natural sunlight



- Seawater as the source
- Average irradiance of 0.8 kW m^{-2}
- Average energy efficiency of 86 %
- 14 kg of water generated after 10 hr
- Significantly reduced ion concentrations safe for drinking

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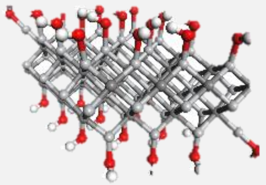
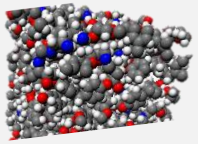
Conclusions and outlook

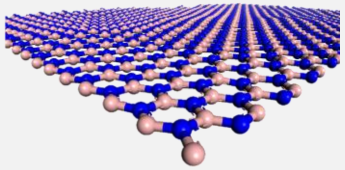
MXene



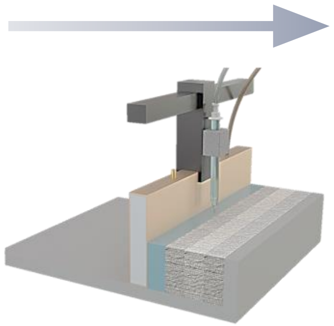
Polymer matrix

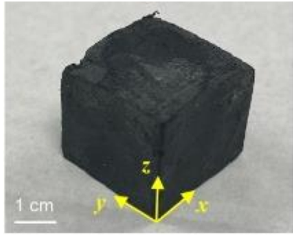


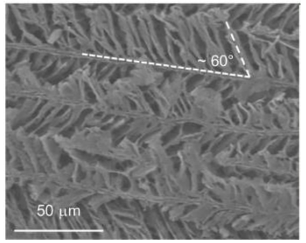
Boron nitride nanosheets (BNNS)

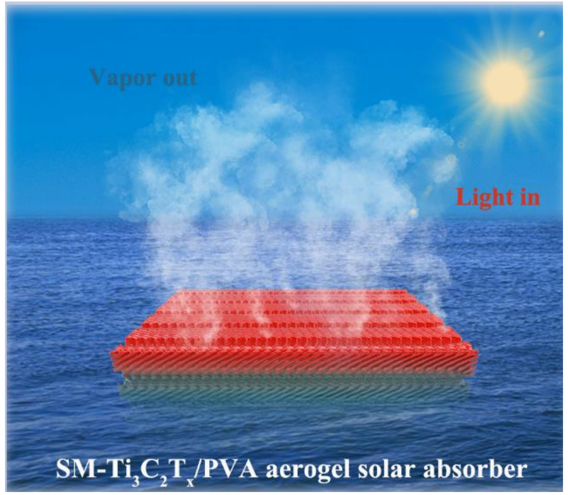


Directional freeze-casting

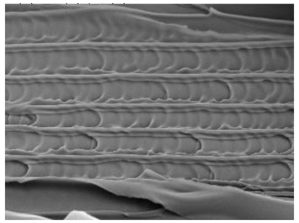








Energy-efficient heating
- Thermally insulating
- Solar absorptive



Energy-efficient cooling
- Thermally insulating
- Solar reflective

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