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Microspray annual meeting 2022

Lowering ice and gas hydrate adhesion



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Faculty



Postdocs (2022)

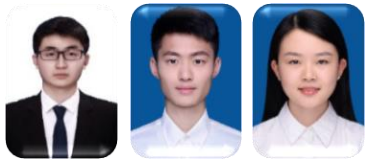


- Nanomechanics
- Interface
- Fracture mechanics

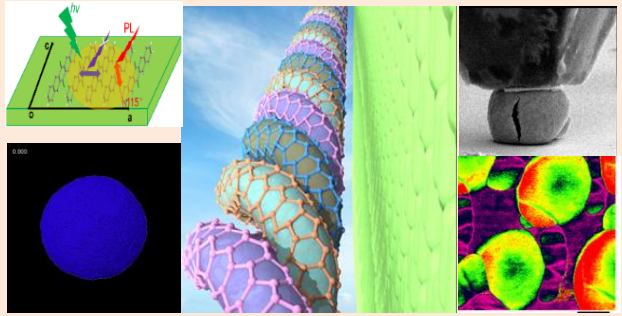
PhD students (2022)



Visiting PhD students (2022)



Nanostructured materials



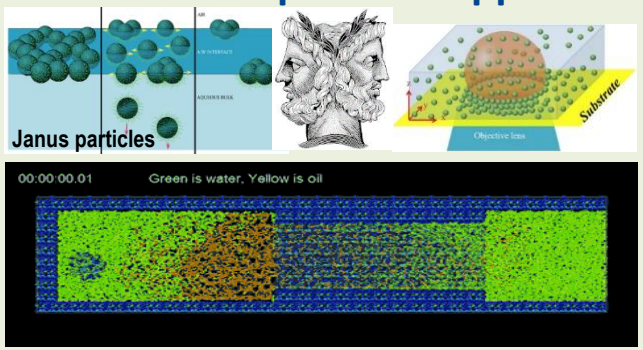
Adv Mater (2021); Carbon (2021); Macromolecules (2021)

Smart phobicity



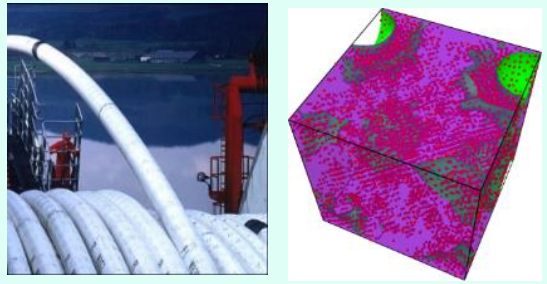
Adv Sci (2021); Appl Mater Today (2022); Chem Eng J (2022)

Nanofluid transport and application



J Petro Sci Eng (2021); Energy (2022); Fuel (2021, 2022)

Structural integrity



Acta Mater (2022); Scripta Mater (2022); Mater Design (2022)

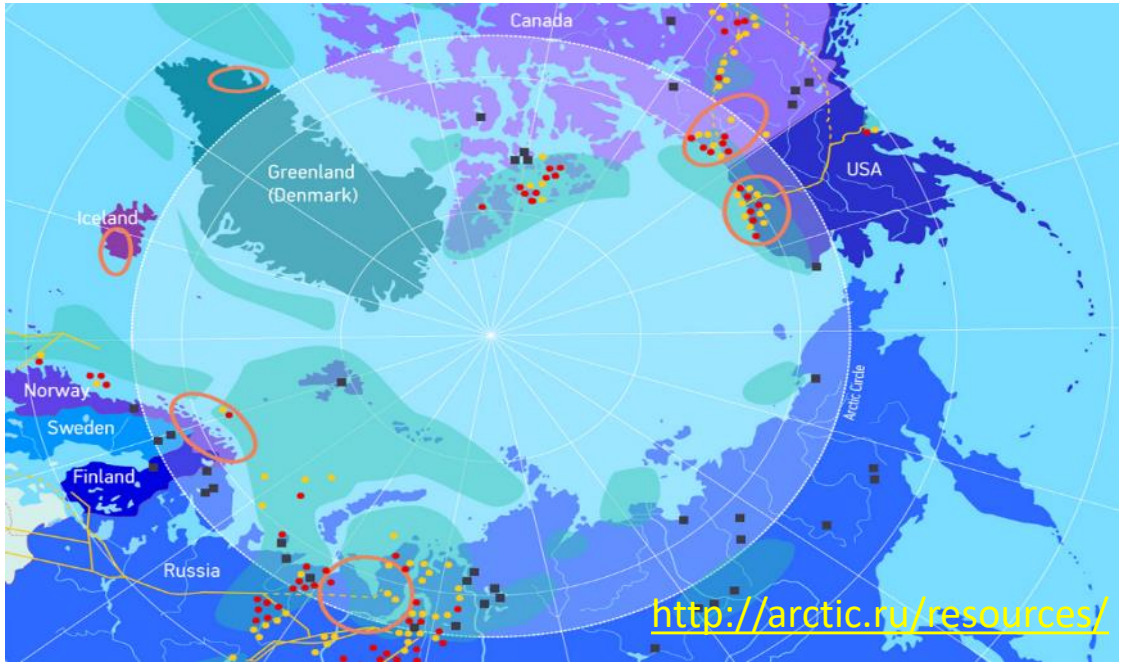
Outline

- Ice and gas hydrate challenges
- Super-Low Ice Adhesion Surfaces (**SLIAS**)
- Fracture mechanics based SLIAS design
- Ice adhesion vs. gas hydrate adhesion
- Concluding remarks and perspectives



https://thebarentsobserver.com/

Ice accretion



Resources in Arctic

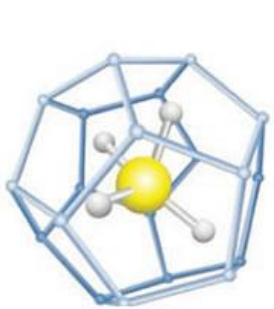
- One tenth of the world's oil;
- A quarter of its natural gas;
- Other minerals.

Ice protection market: $10.17 billion (2021)



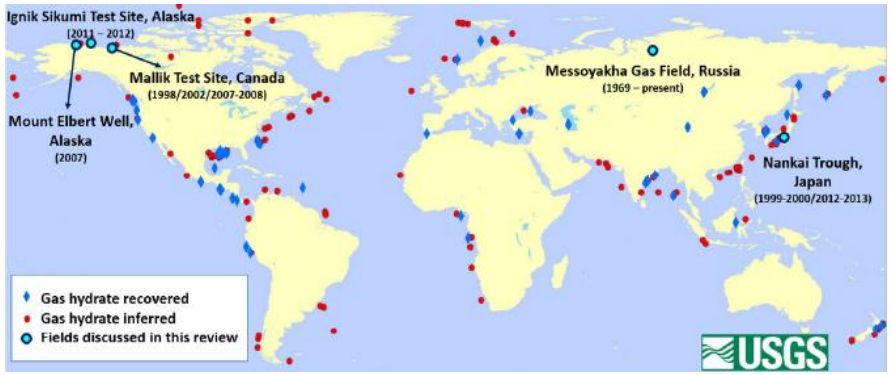
Gas hydrate plug

Future energy material



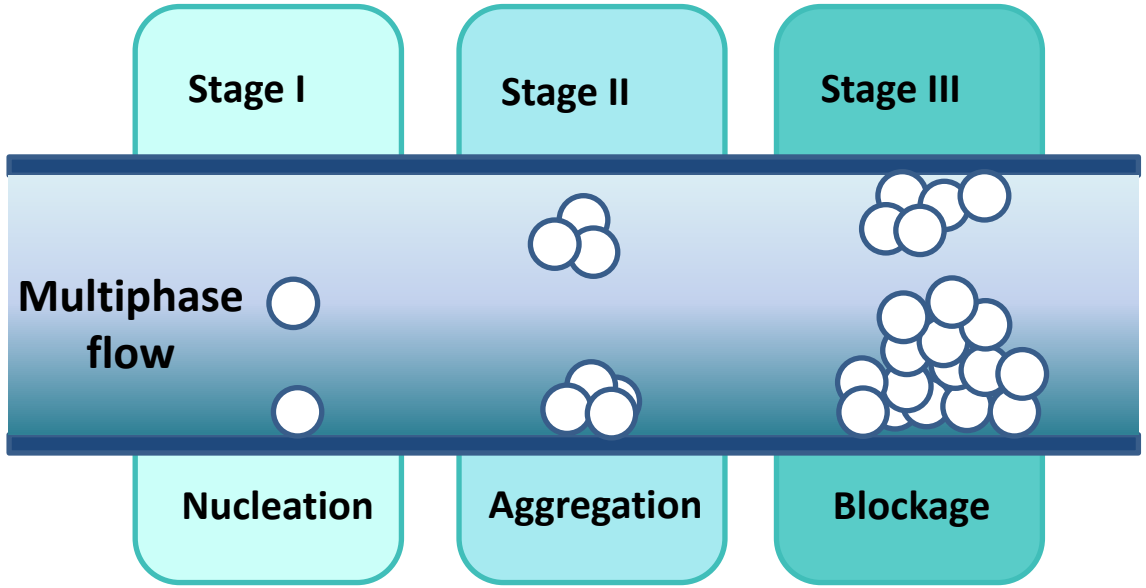


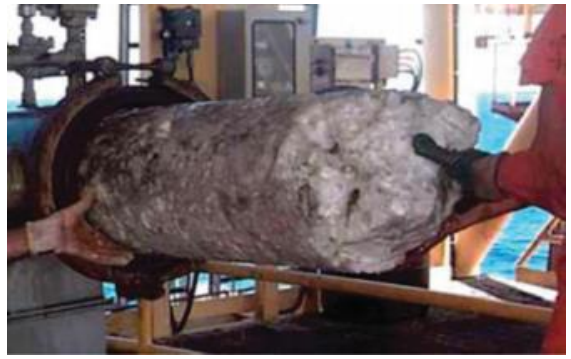
Flammable ice



Resource distribution

Applied Energy, 2016, 162, 1633-1652



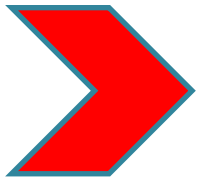




Images from google

Deicing/Anti-icing strategies

Active de-icing





Mechanical

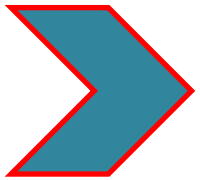


Heating



Chemical

Passive anti-icing



Repelling coming water

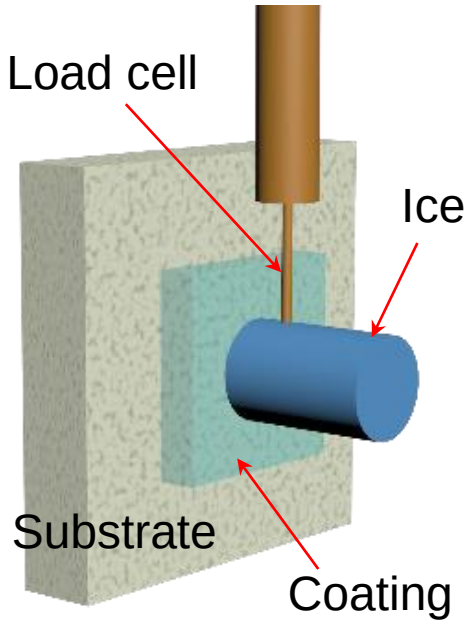
Delaying droplet freezing time

Preventing frost formation

Lowering ice adhesion

How low is low enough?

- The tensile strength of ice: (**0.7-3.1**) MPa
- Measured ice adhesion: (**0-1.5**) MPa
- Typical metallic surfaces: ≥ **600** kPa
- **Non-textured fluorinated surfaces: ≥ 200 kPa.**
- **Icephobic: ≤ 100 kPa**
- **Low ice adhesion surface: ≤ 60 kPa**
- Strong breeze detaches ice on an airplane: ≤ **27 KPa**
- **Super Low ice adhesion surface (SLIAS): ≤ 10 kPa**
- **Sea spray ice < 5 kPa on Al**



$$\tau_c = \frac{F_{max}}{A} = \frac{\rho L^3 g}{L^2} = \rho L g$$

Meuler et al. ACA AMI 2010, 2: 3100
He et al. **Sci Rep**, 2017, 7:42181
He et al. **Soft Matter**, 2017, 13, 6562-6568

How to lower the ice adhesion?

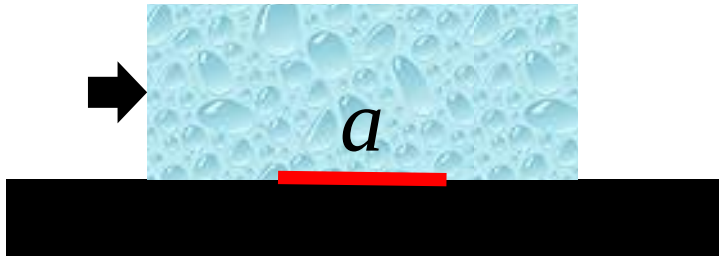
Young's modulus

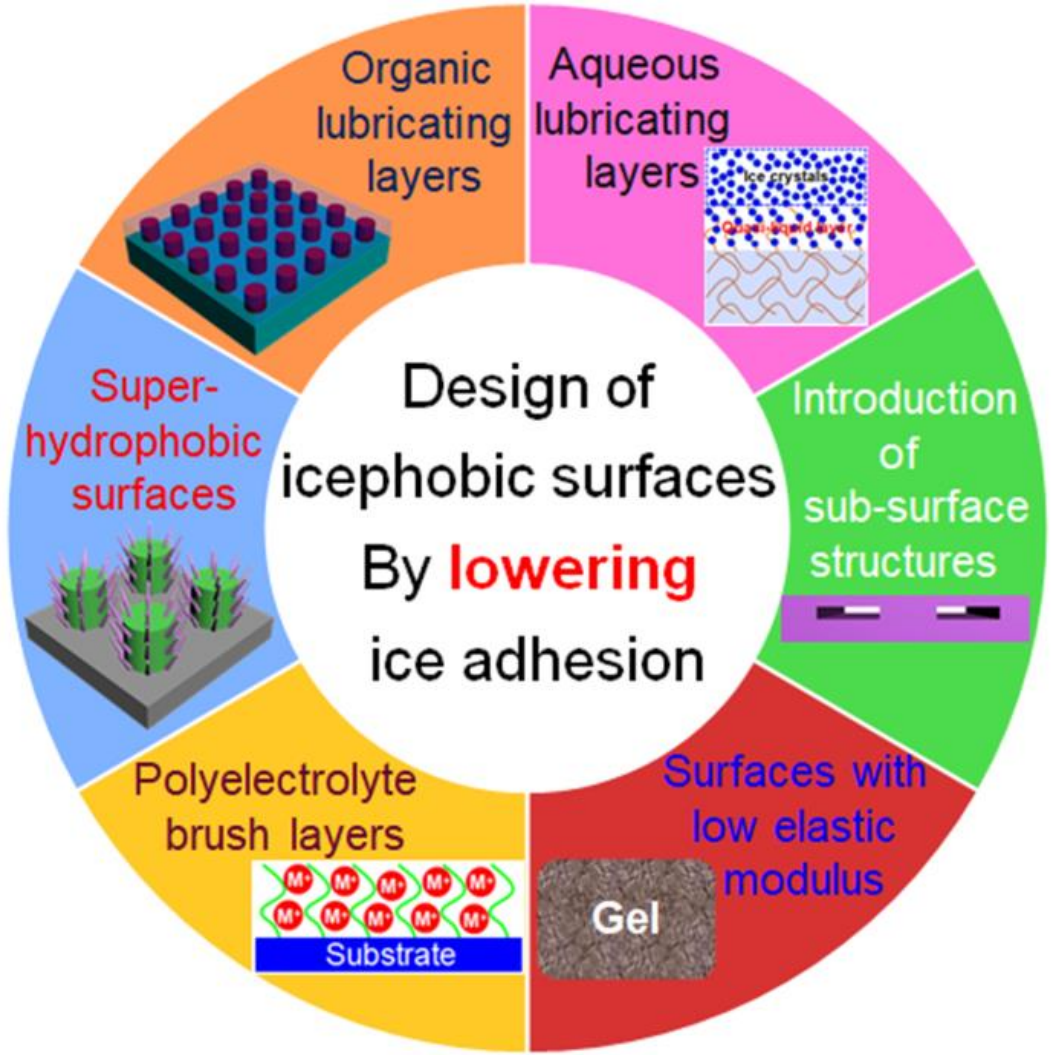
Surface energy

Shear strength $\tau_c = \sqrt{\frac{E \cdot G}{\pi \cdot a \cdot \Lambda}}$

Crack length

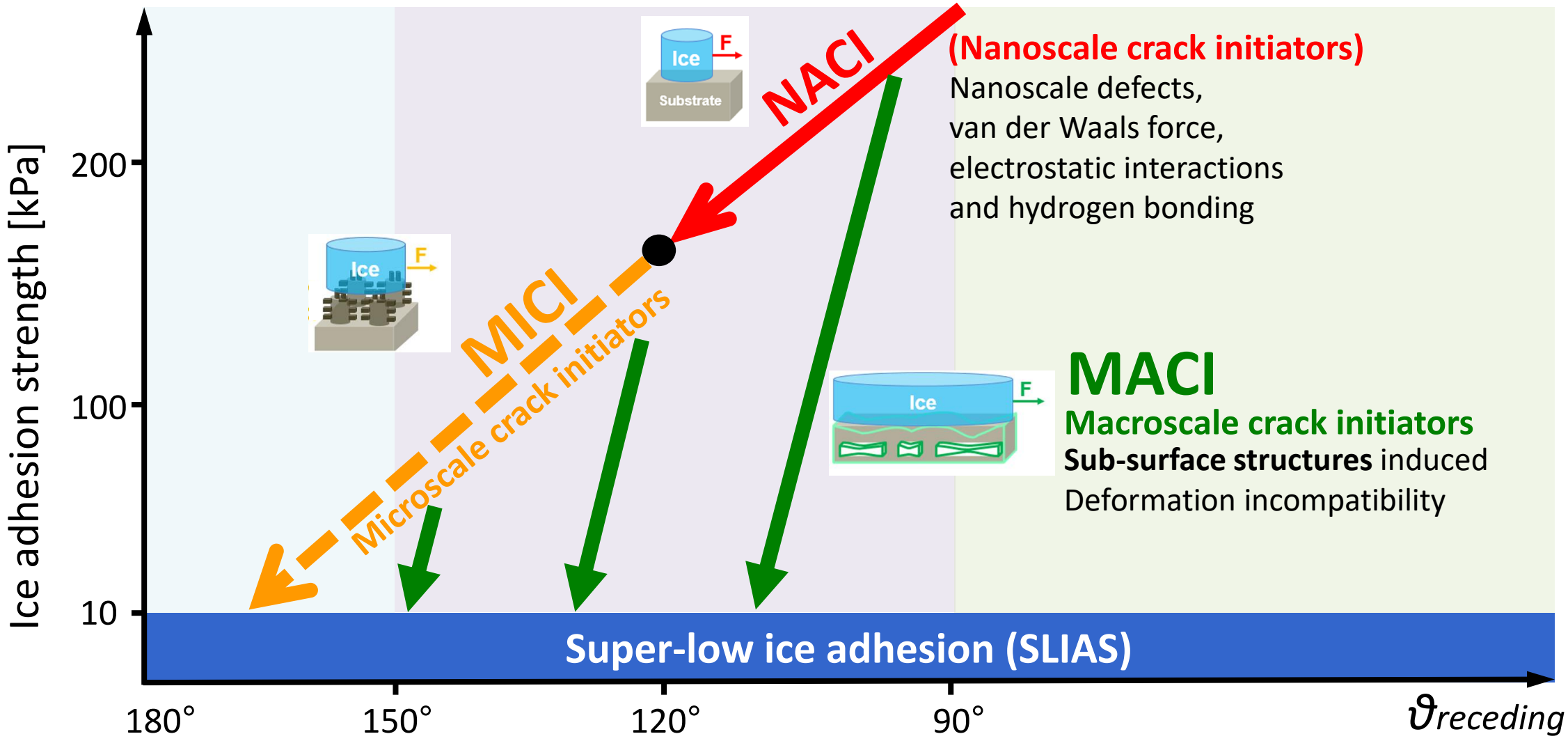
Boundary dependent constant





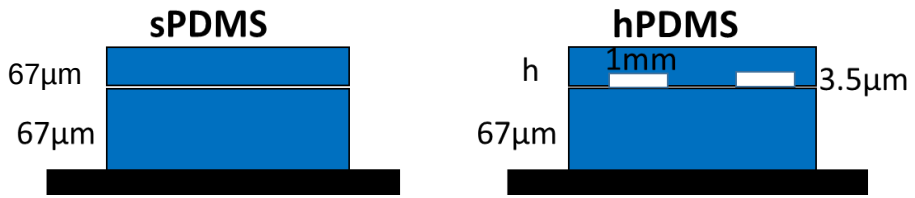
He et al, **Prog Org Coat**, 2020, 105737

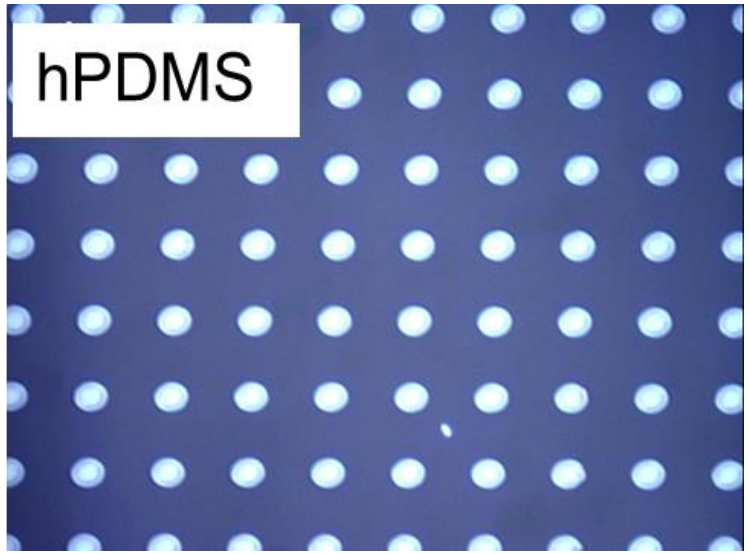
Crack initiator mechanism

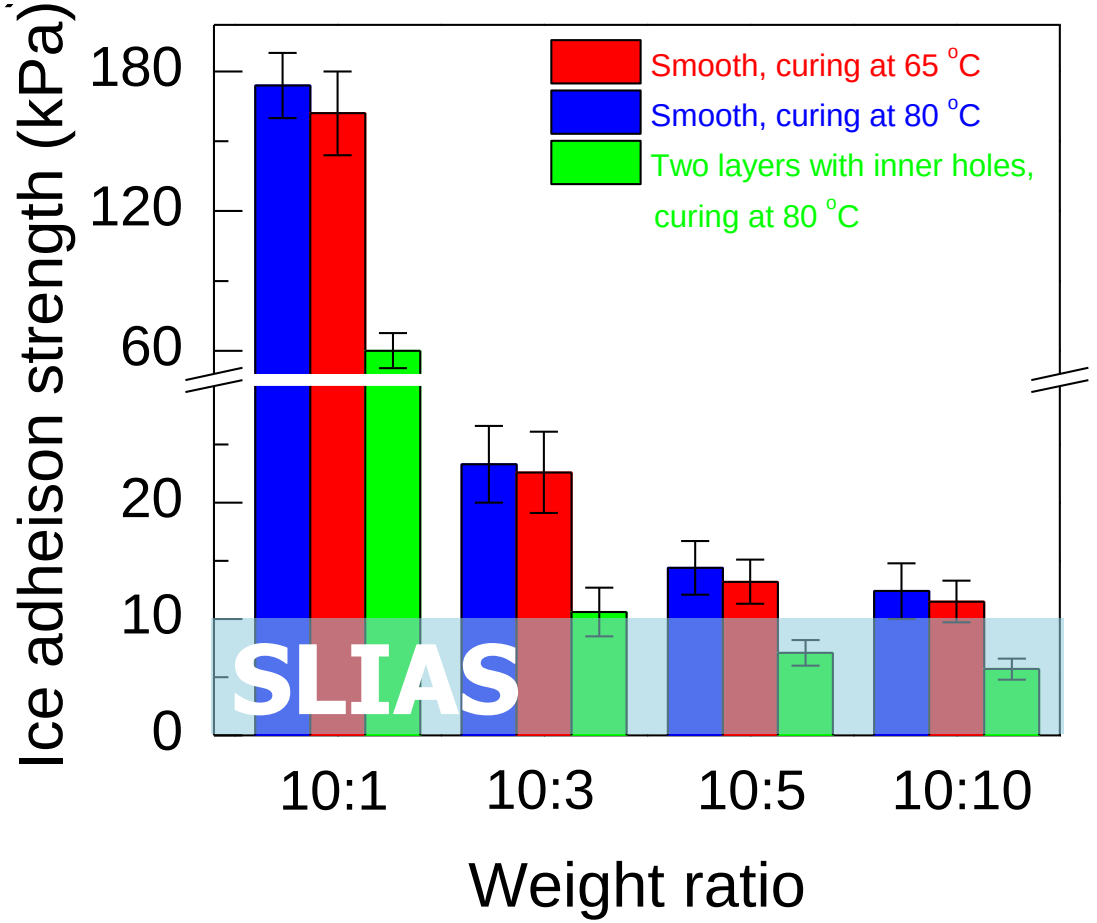


He et al. **Soft Matter**, 2017, 13, 6562-6568

MACI-based PDMS coatings



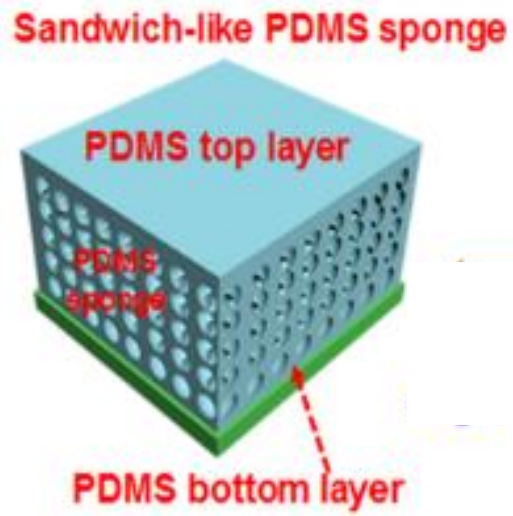


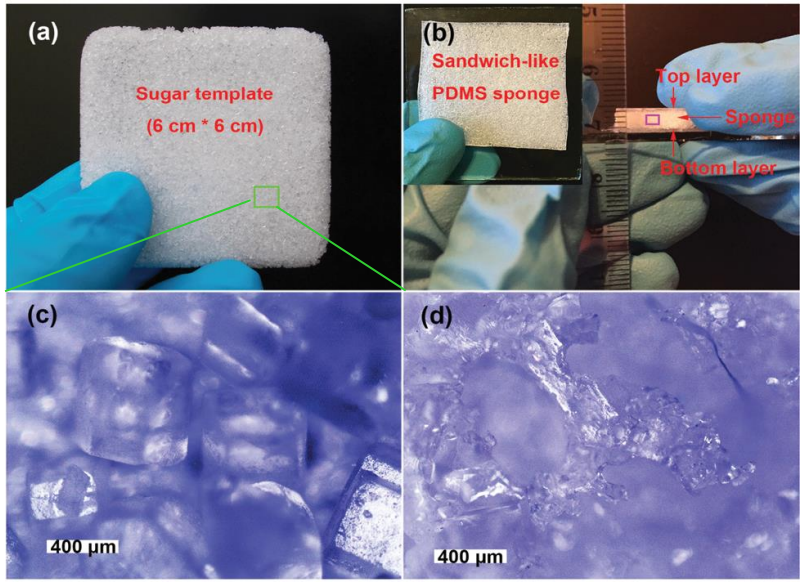


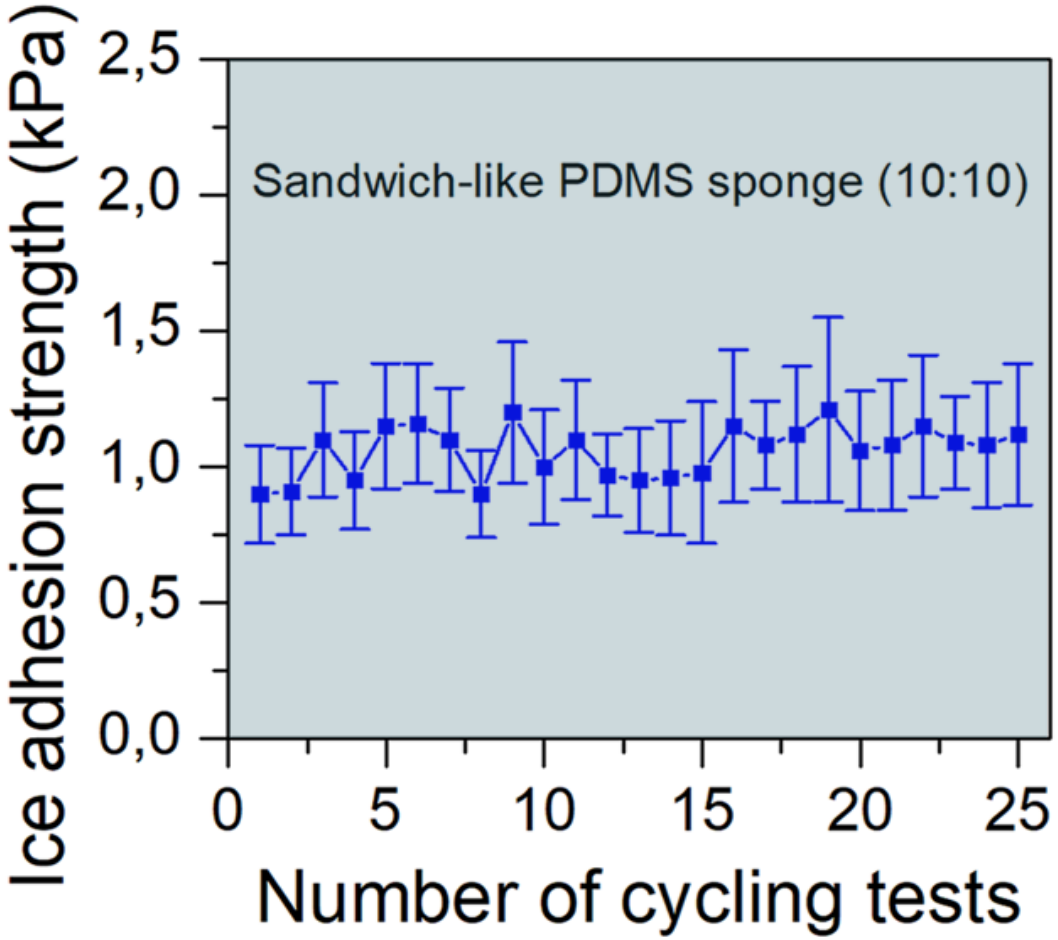
x-linking density: 333 [mol/m³] 222 [mol/m³] 162 [mol/m³]

He et al. **Soft Matter**, 2017, 13, 6562-6568

Sandwich-like PDMS sponge





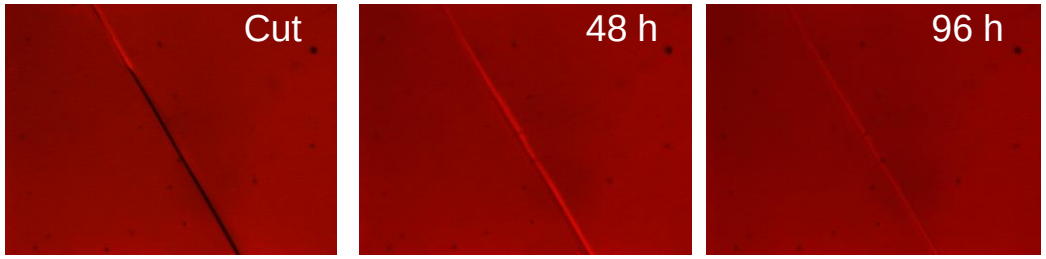


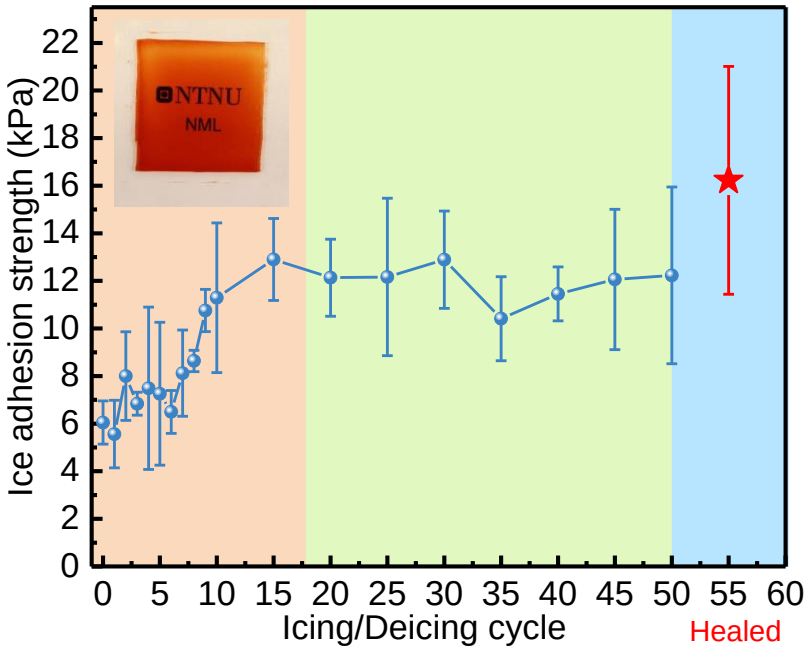
Durable SLIAS around 1 kPa

He et al. ***Soft Matter***, 2018, 14, 4846-4851

Self-healing elastomer

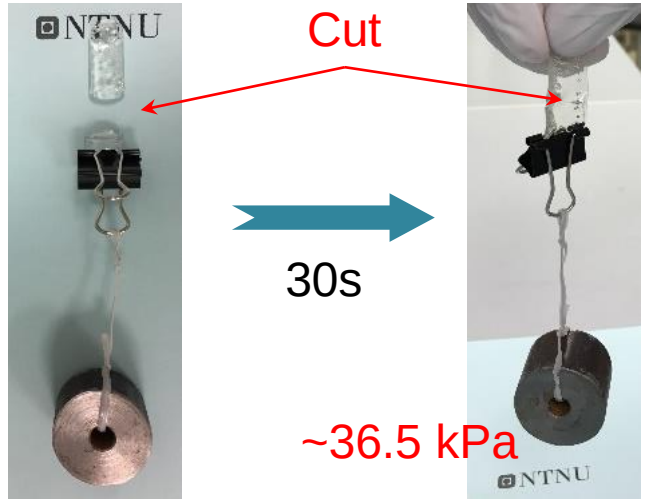
First self-healing anti-icing surface

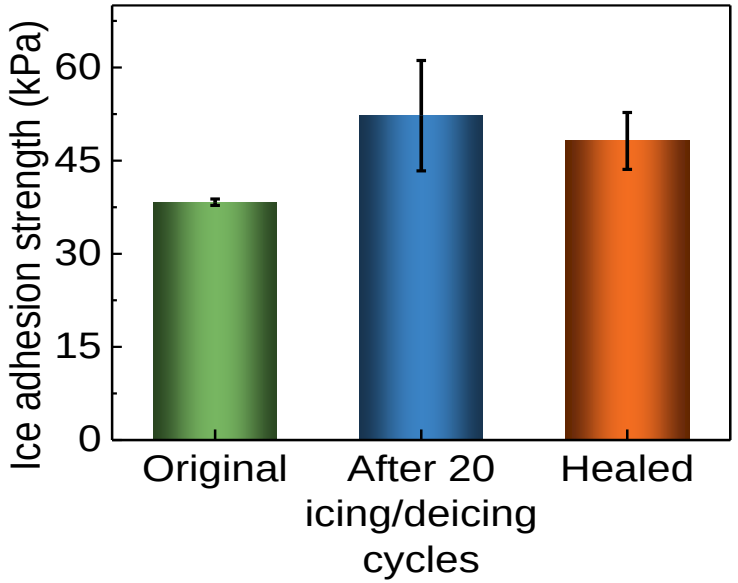




Zhuo et al, ***ACS Appl Mater Interfaces***, **2018**, *10* (14), 11972–11978

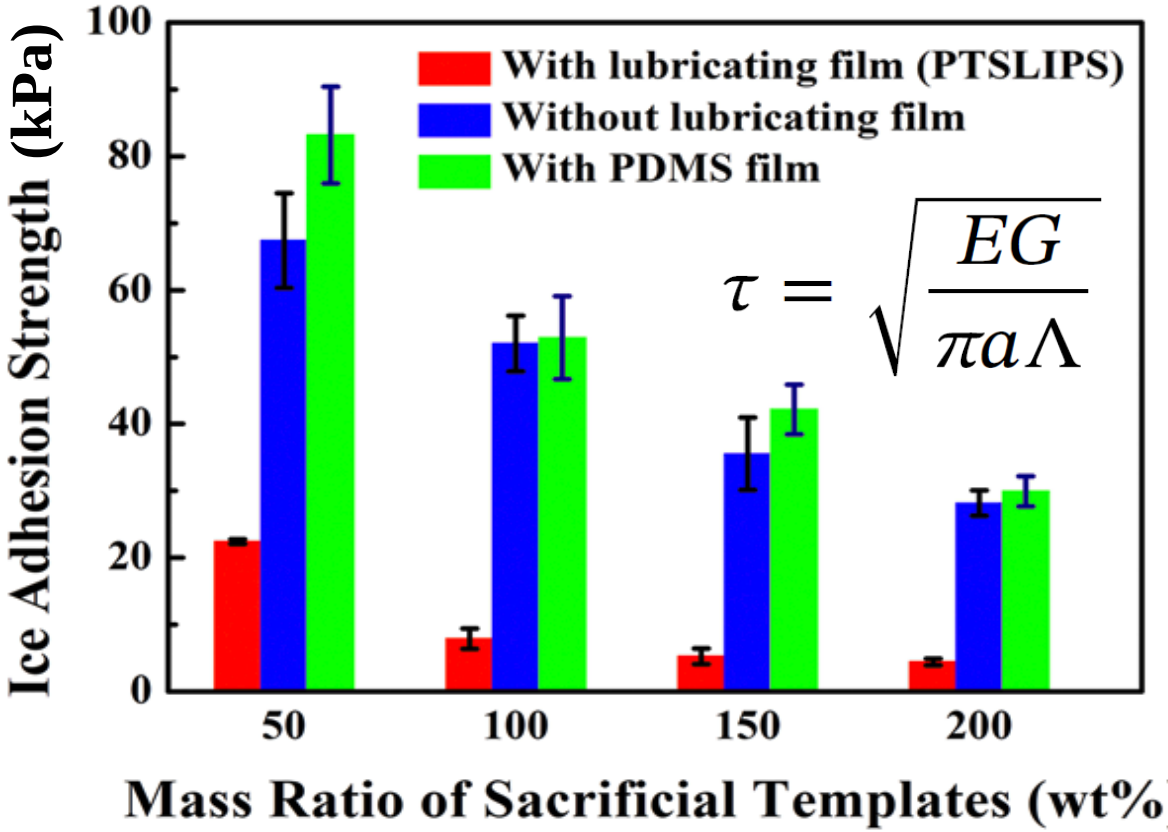
Ultrafast self-healing & transparent surface

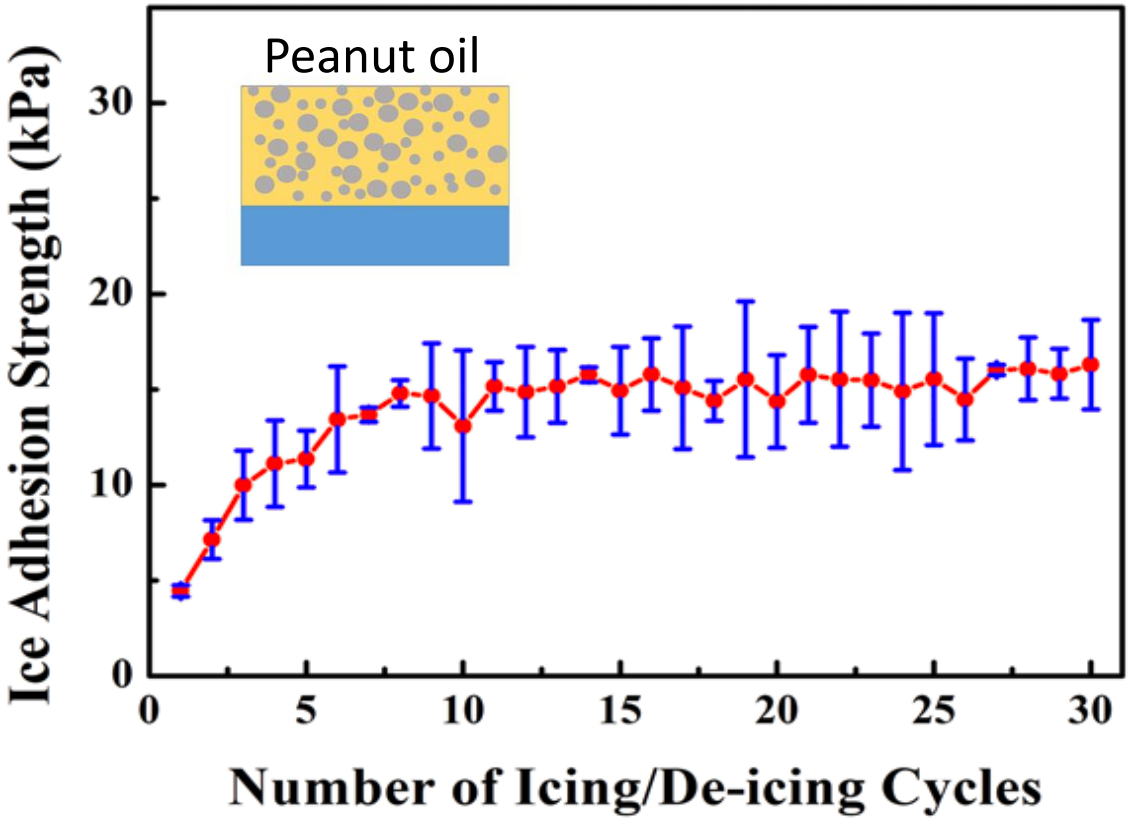




Zhuo et al, ***Appl Mater Today***, **2020**, *19, 100542*

Phase transition lubricant

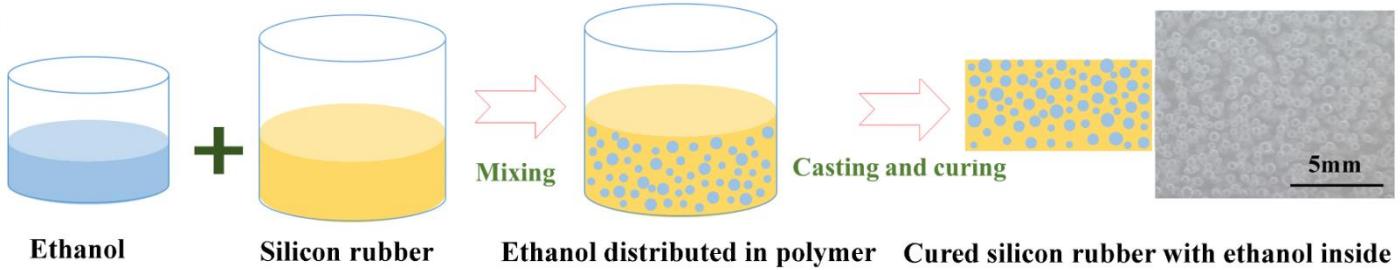


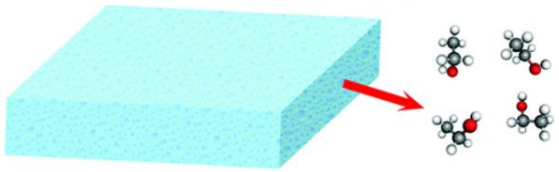


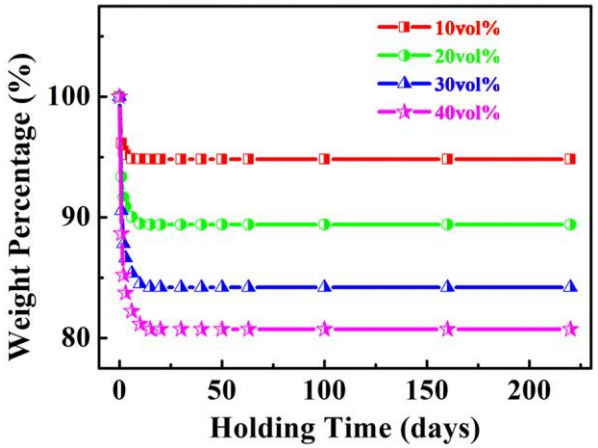
- Super low ice adhesion strength: 4.5 kPa
- Ice adhesion strength after 30 icing/de-icing cycles: ~ 16 kPa

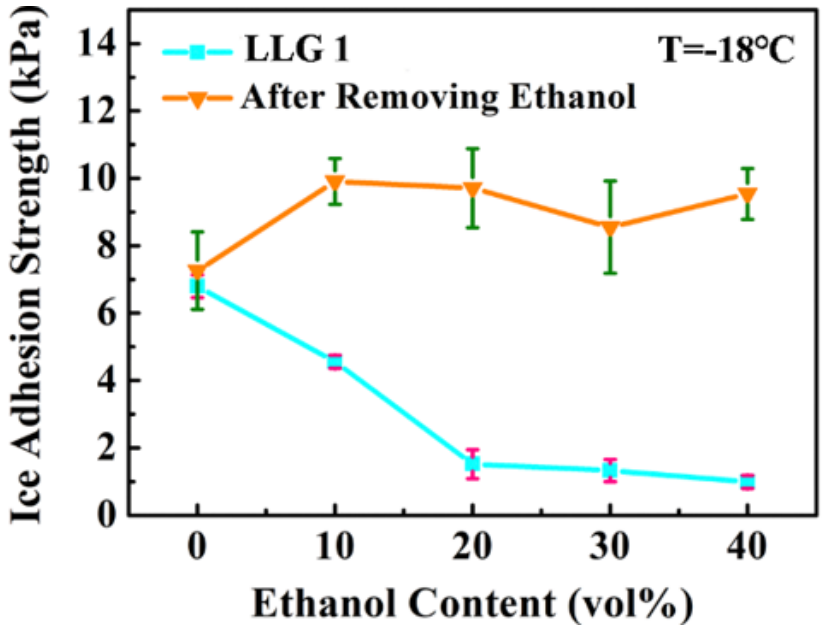
Wang et al. **Chem. Eng. J.** 2019, 360: 243

Liquid layer generator (LLG)

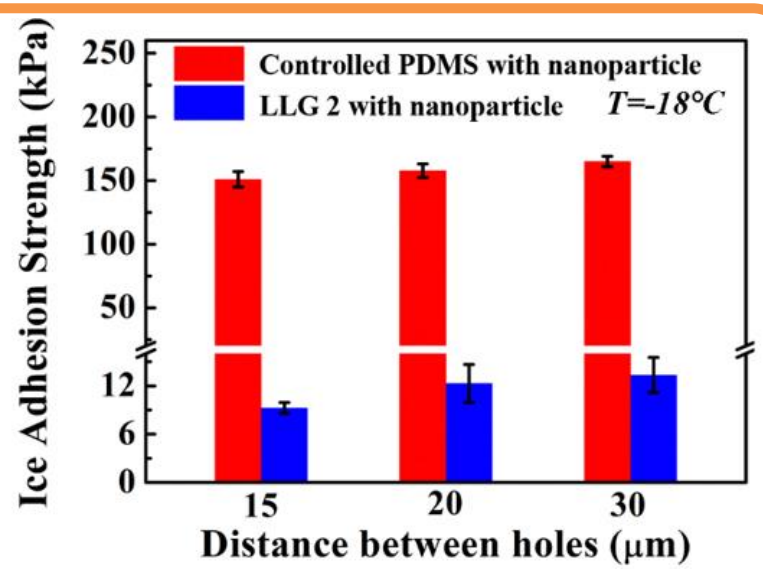


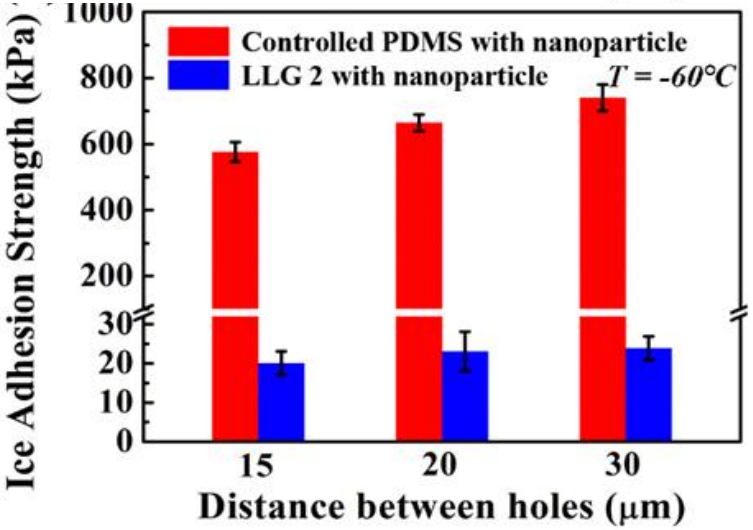




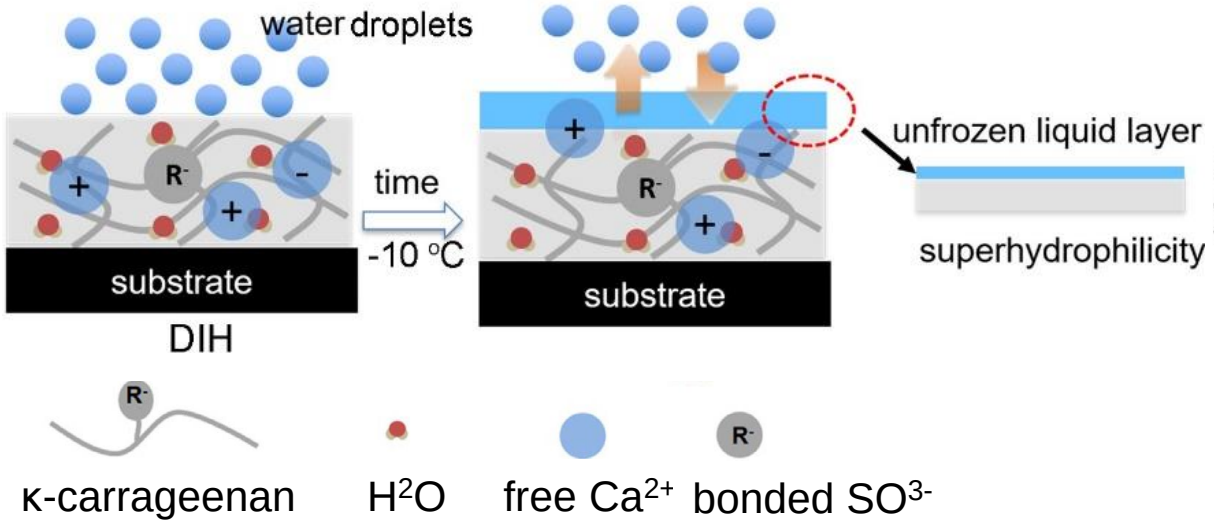


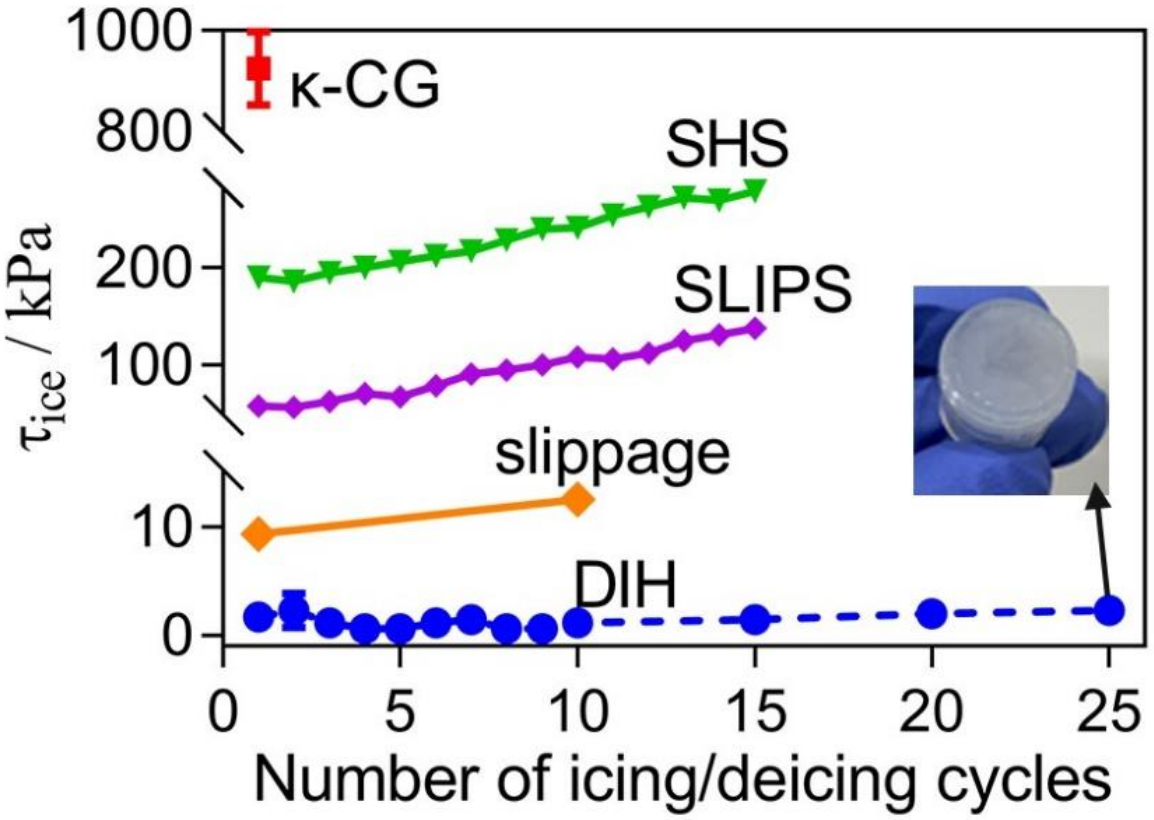
Wang et al. **Mater. Horiz.** 2019, 6: 2063





Dual-ionic hydrogels (DIH)

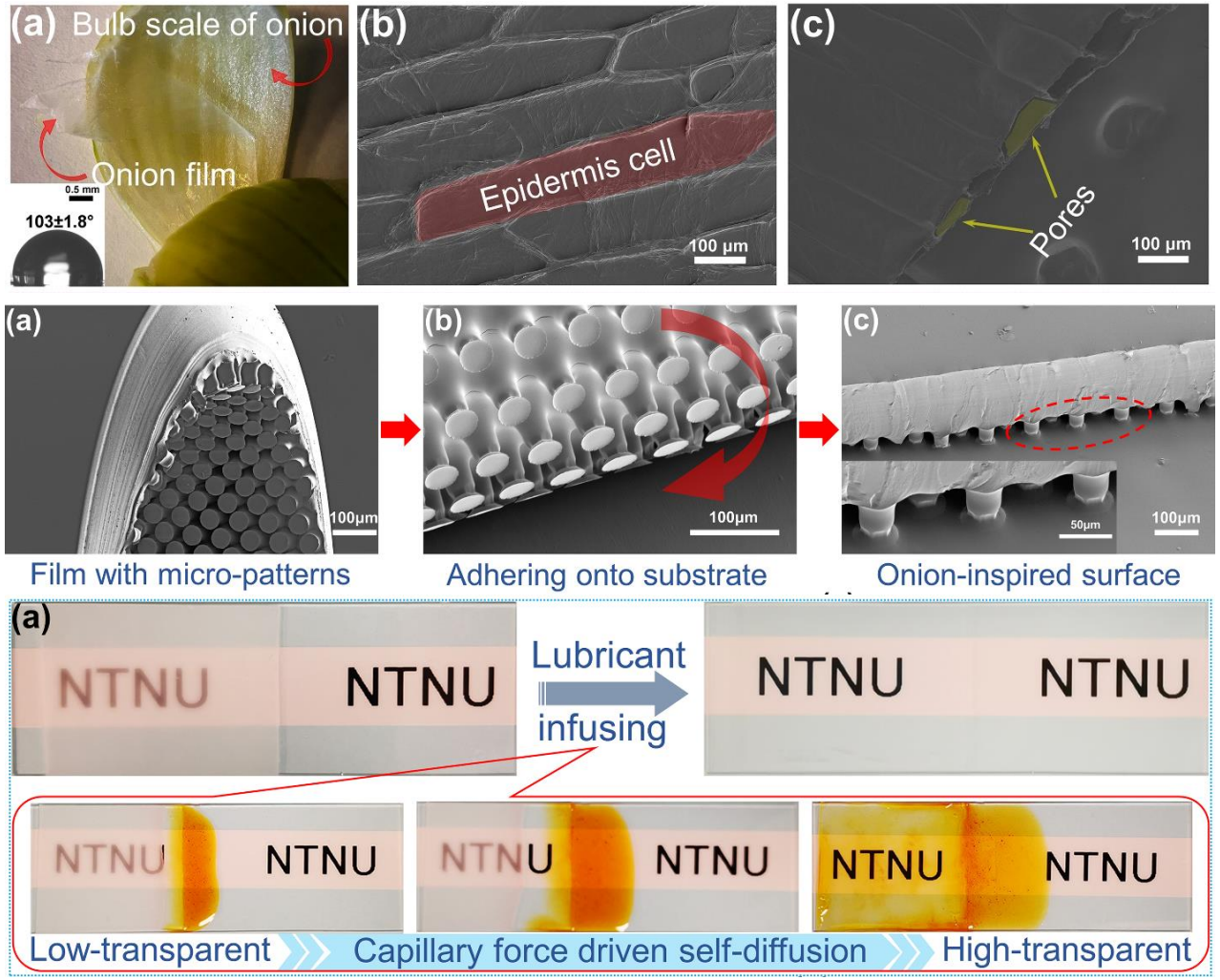


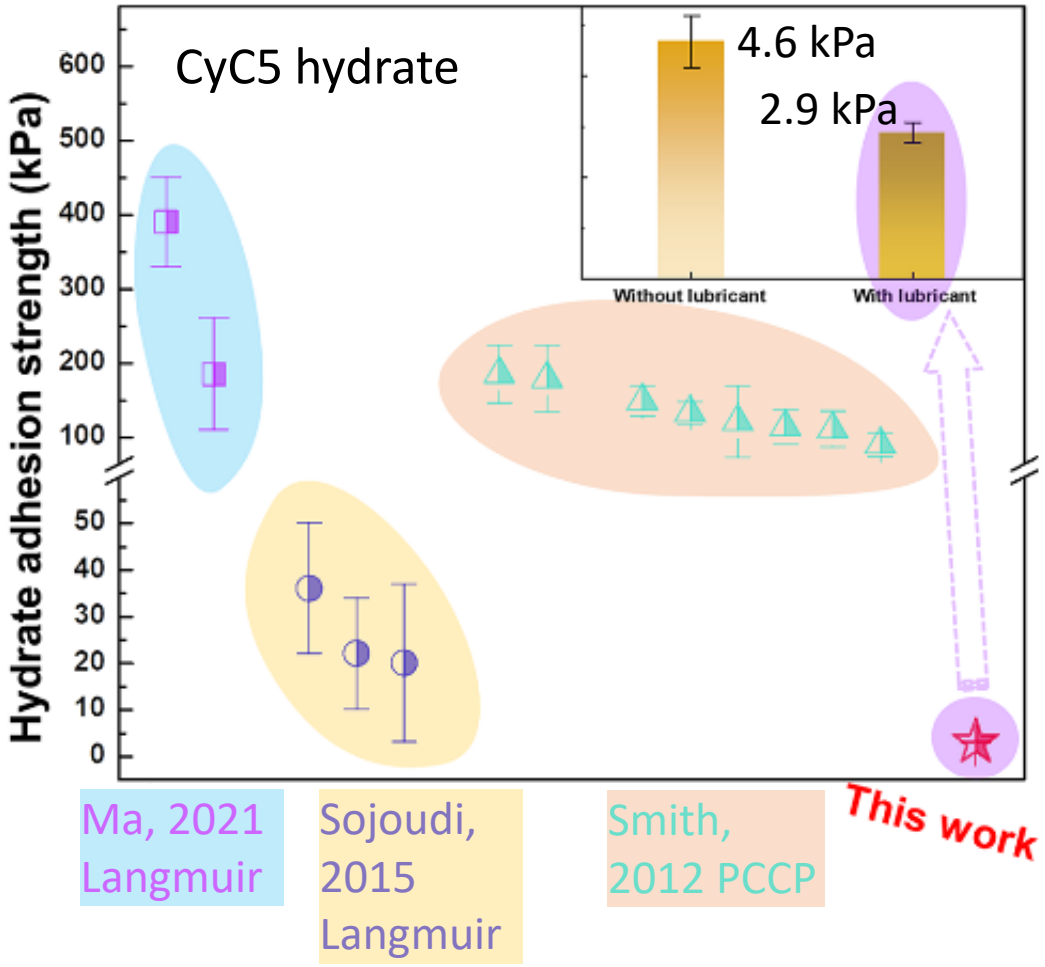


Li et al, ***Appl Mater Today***, *2022, 101367*

MACI enabled low hydrate adhesion surface

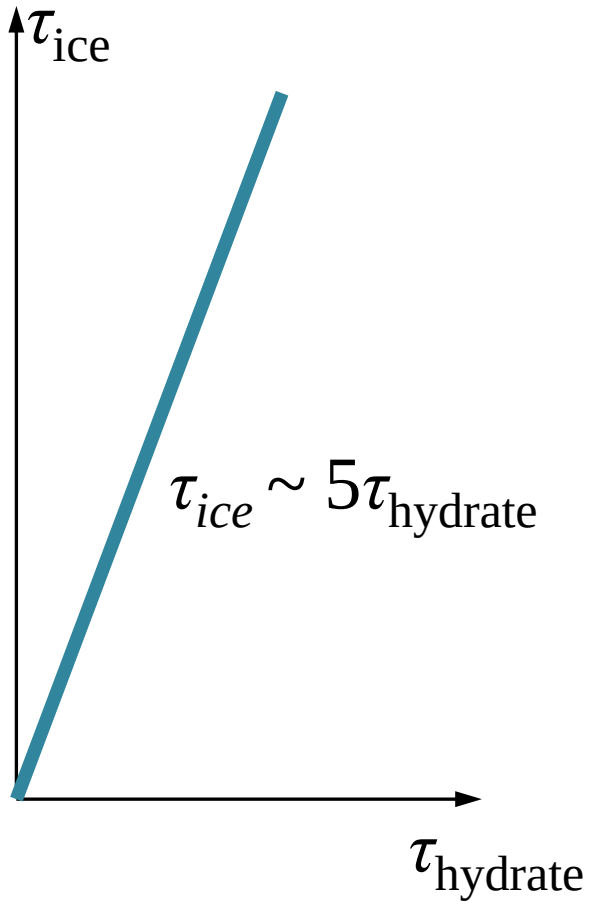
Onion-inspired surface design

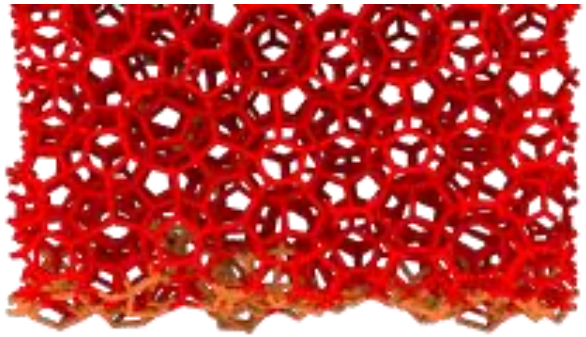




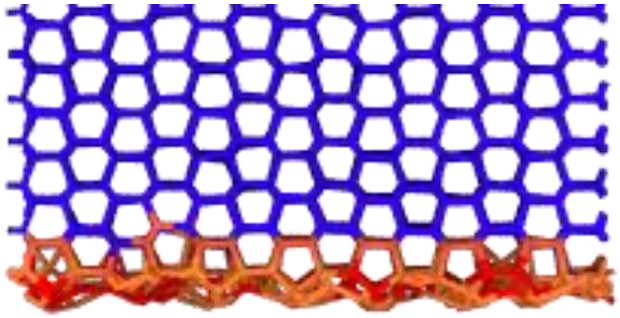
Wang et al. **Chem Eng J.** 2022, 437: 135274

Ice adhesion vs. hydrate adhesion

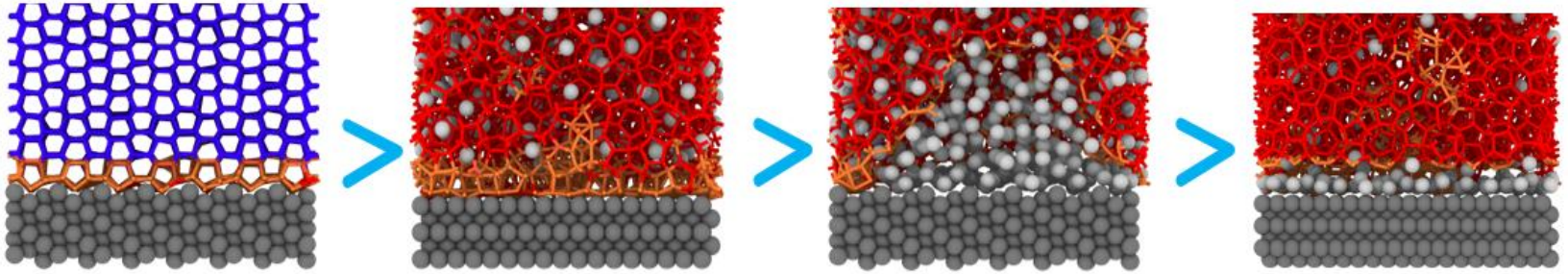




hydrate--low areal density



ice--high areal density

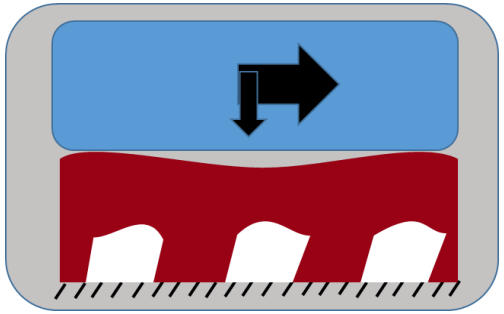


Interfacial adhesion strength

Concluding remarks

- Super-low ice adhesion surface (SLIAS) < 10 kPa
- Powerful mechanism to weaken the ice/hydrate-solid interface

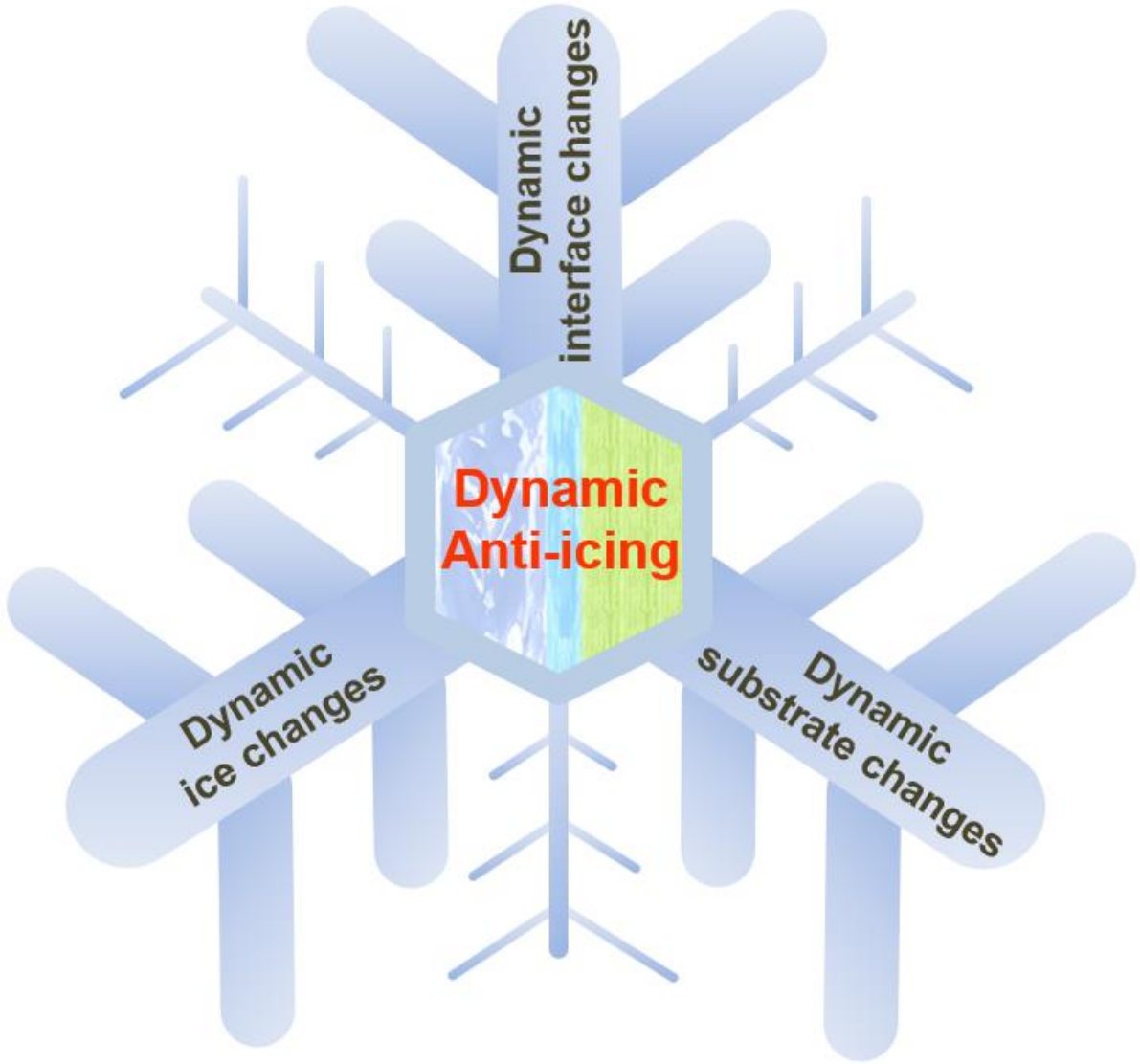
MACI



$$\tau_c = \sqrt{\frac{E \cdot G}{\pi a \Lambda}}$$

- MACI can be easily incorporated with other icephobic mechanisms
- Ice adhesion strength is 5 times hydrate adhesion strength?

Perspectives



Acknowledgment

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Dr. Feng Wang, SCINM, CN

Dr. Verner Håkonsen, NTNU

PhD candidate Rui Ma, NTNU



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