Nanometers to Motorcycles

Heat transfer across scales

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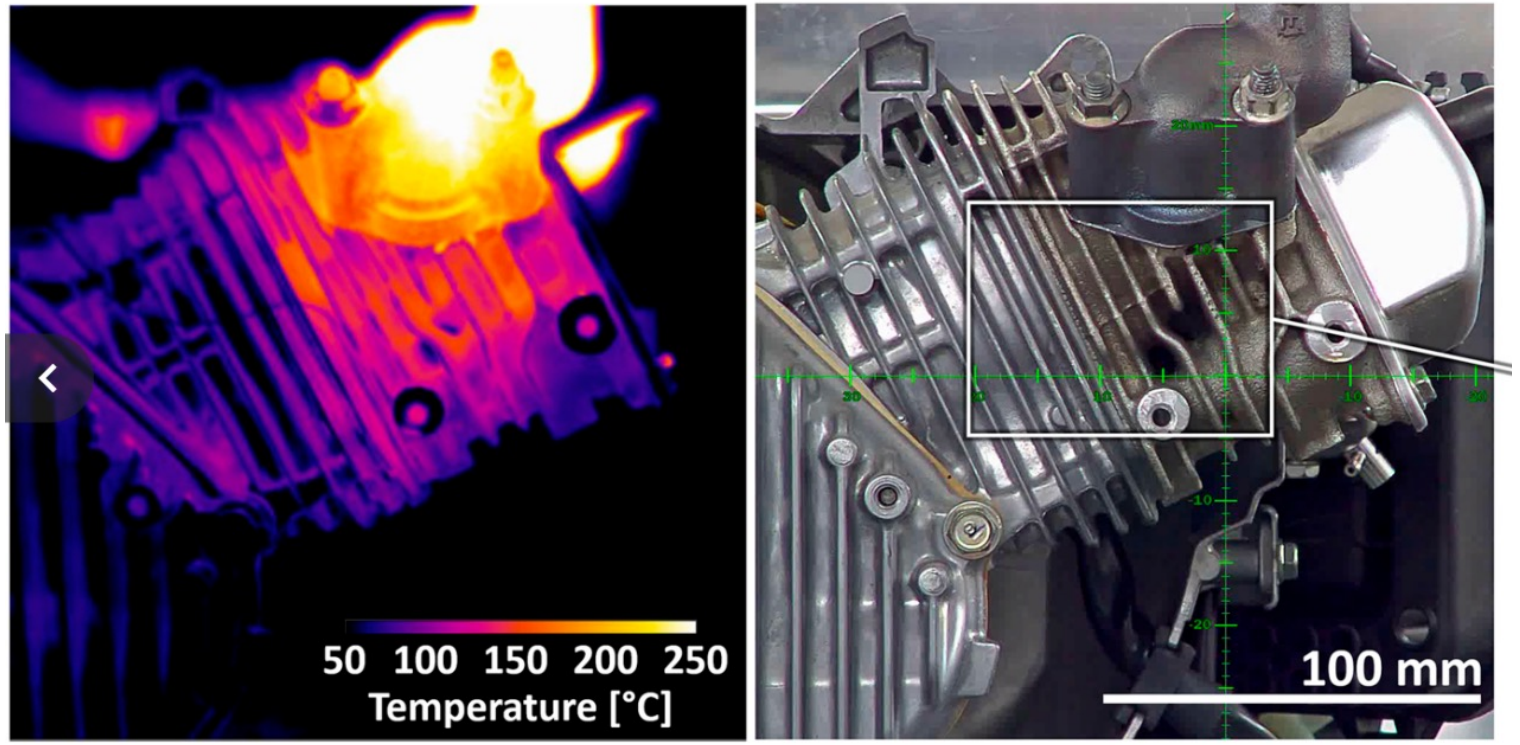
Heat transfer matters in motorcycles

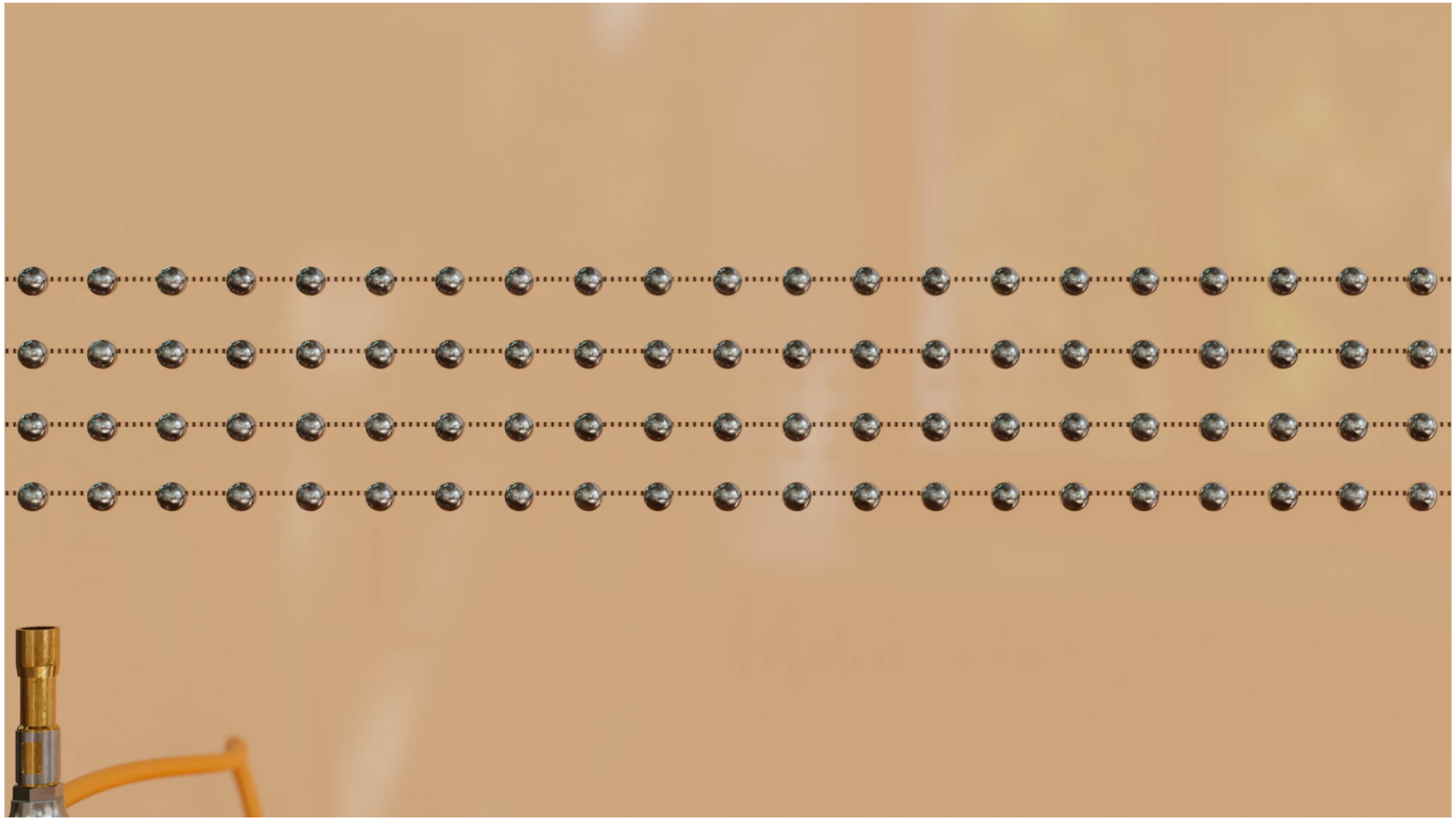


Wissink et al., PNAS (2020)

- Extreme temperatures in the combustion chamber: gases can get as hot as ~2,200 C!
- Leads to high temperatures in the engine block → heat transfer to chassis

  critical for: safety, mechanical integrity, comfort

Zoom into the nanoscale: what is heat?



Tec-science.com

“phonons”

Really high frequency atomic vibrations that carry heat in electrical insulators

How is heat conducted in metals?

Tec-science.com

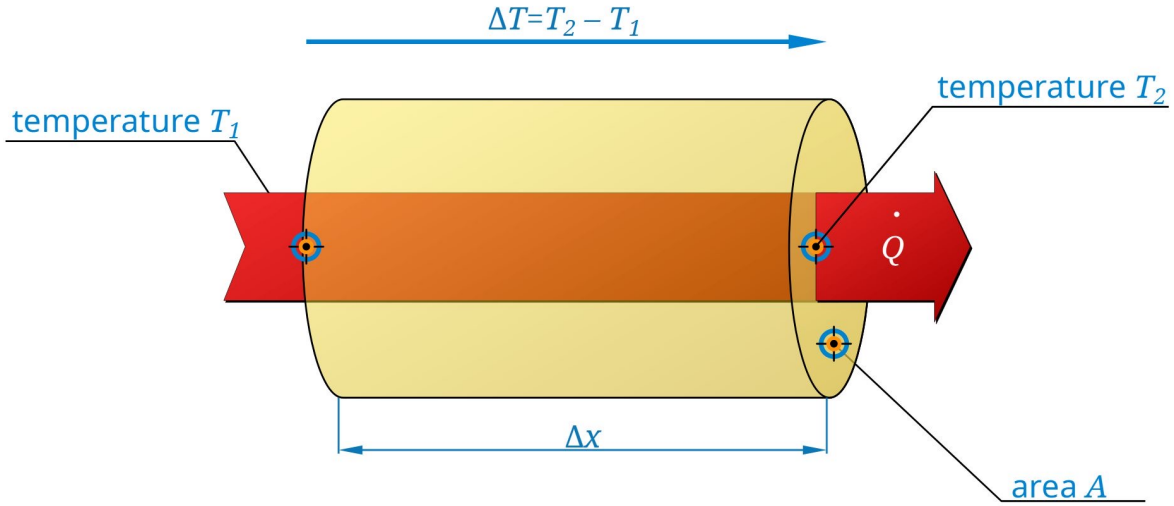
electrons

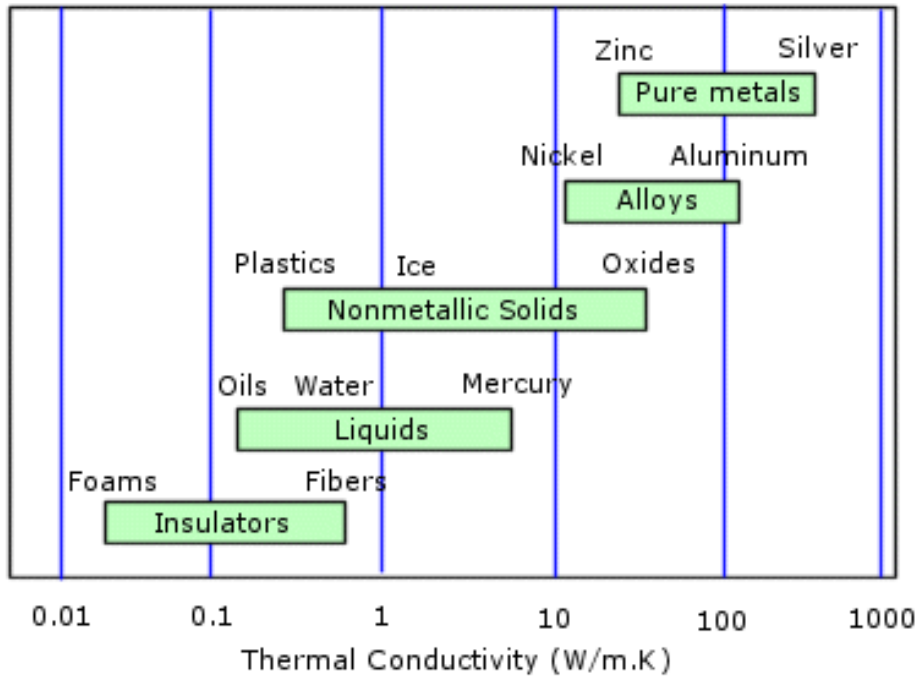
Charges carry heat (and electricity!) in metals

Bulk vs nanoscale: heat conduction

- Bulk: Fourier Law

$$q = -\kappa . \frac{\Delta T}{\Delta x}$$



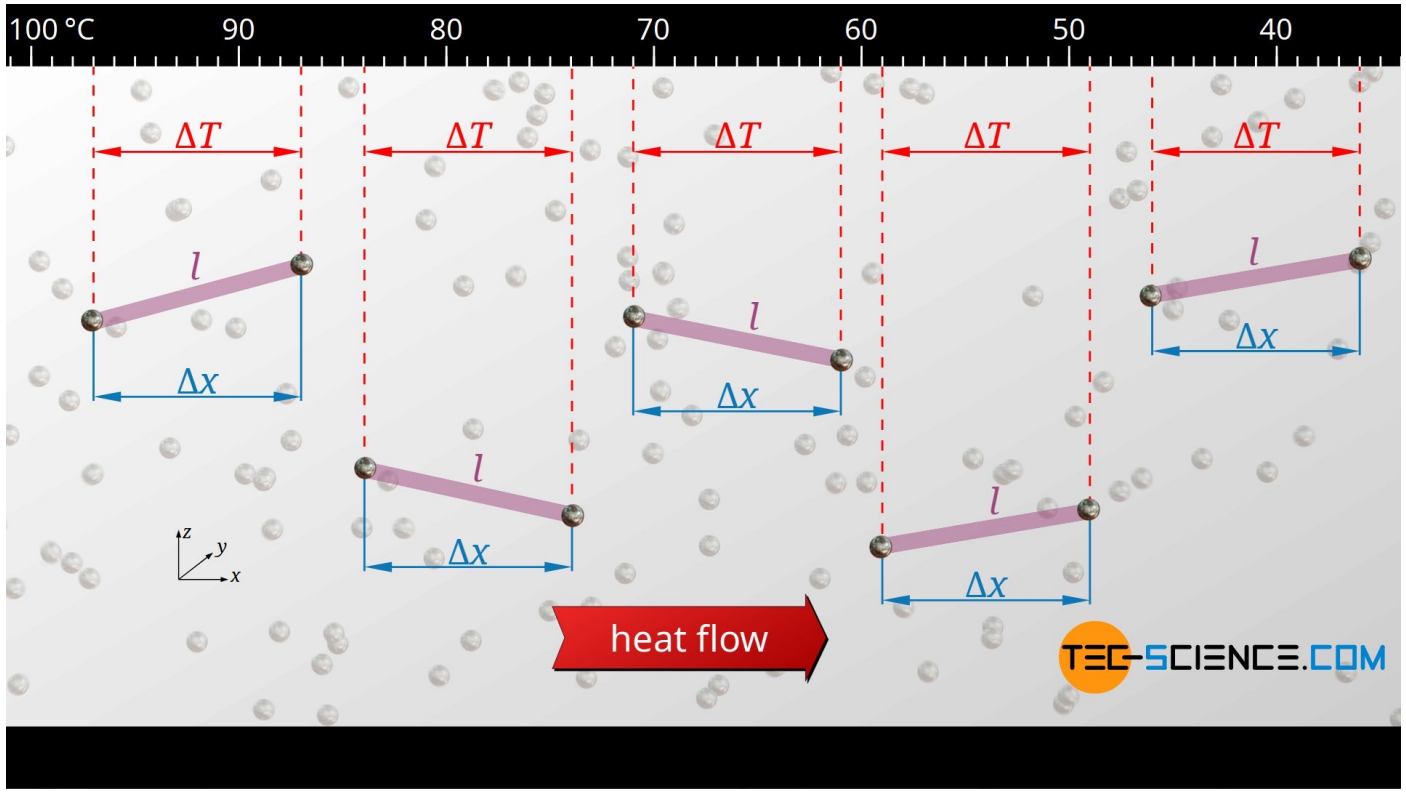


TEC-SCIENCE.COM

Solidworks.com

Bulk vs nanoscale: heat conduction

- But this breaks down for nanoscale materials!



1. Thermal barrier coatings

Piston crown

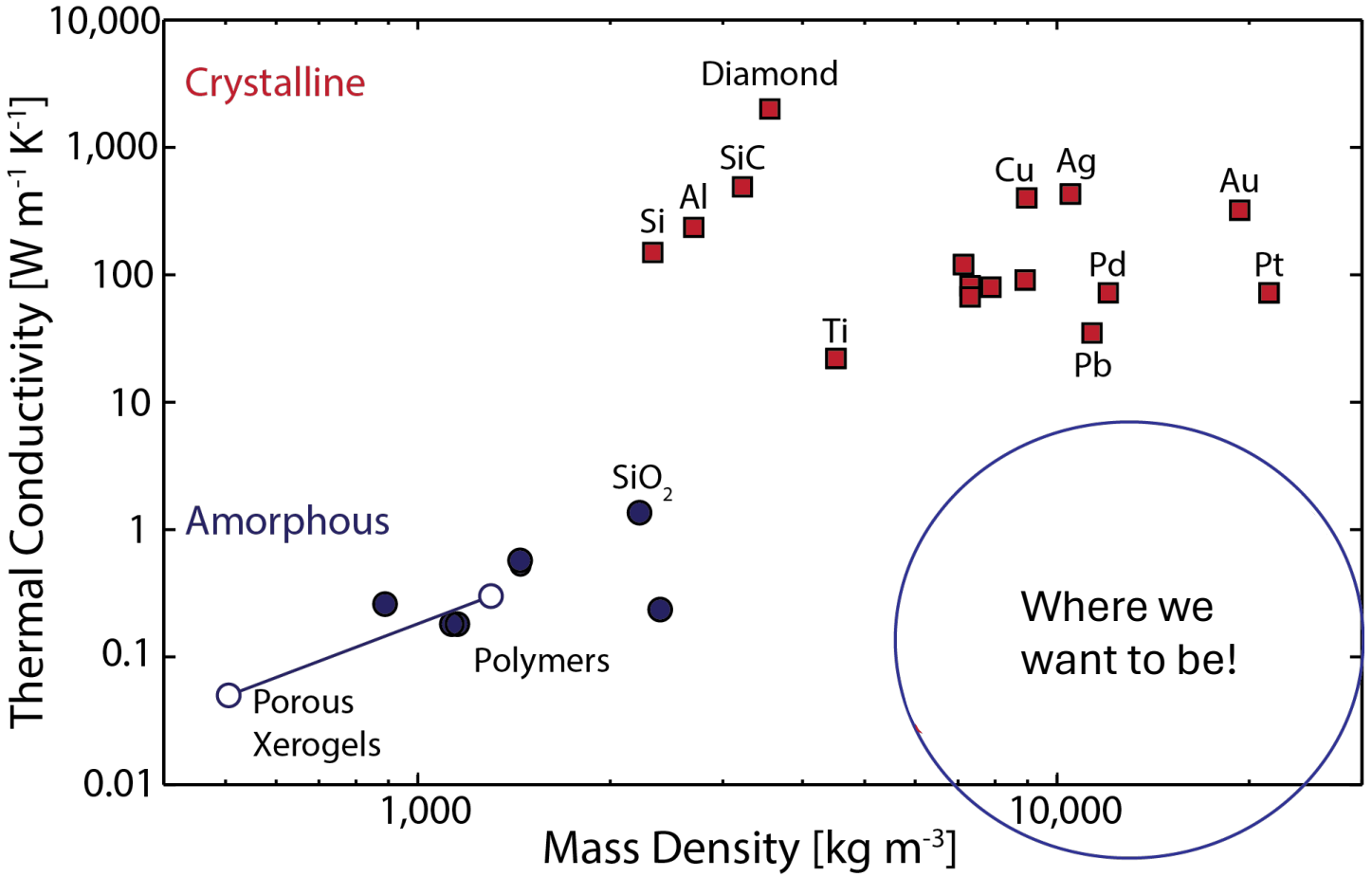
Need:
Mechanically rigid (dense) thermal insulators

Must insulate the piston from the hot combusting gases!

- Retain heat in the gas: efficiency
- Reduce thermal expansion and fatigue

Jepistons.com
Imeche.org

This is not easy! Materials design challenge

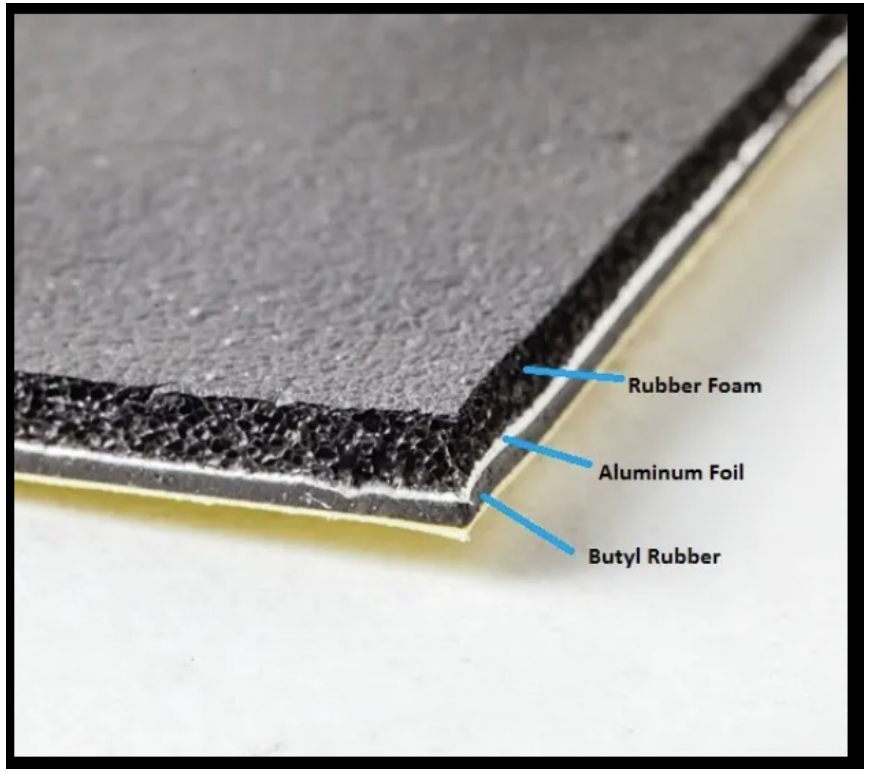


Barako, PhD dissertation
Stanford University

- Most thermal insulators are mechanically soft – bad!

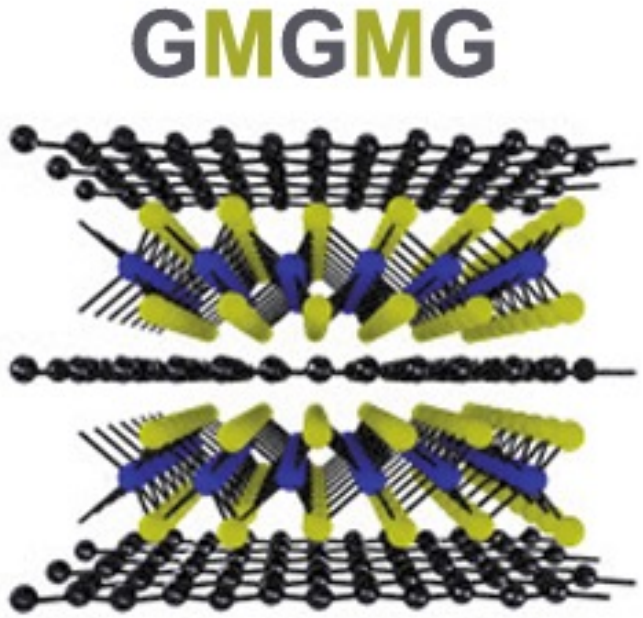
Inspiration from acoustics

- Multilayers block sound: acoustic impedance



Alibaba.com

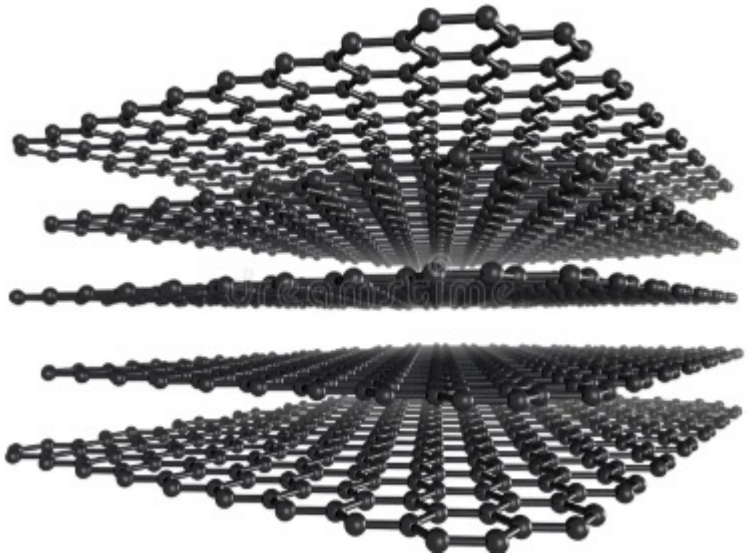
- Extend this idea to the atom scale!
- Alternate light and heavy atoms

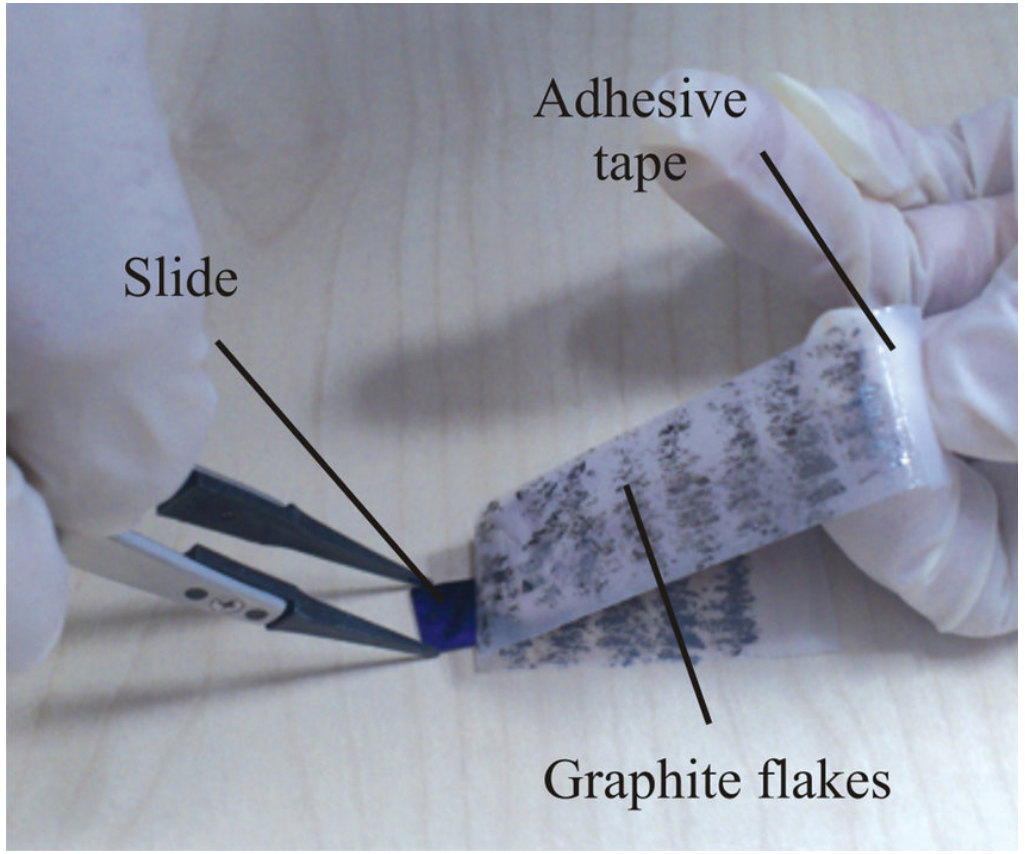


Sood et al., ACS Nano (2021)

Fascinating world of 2D materials

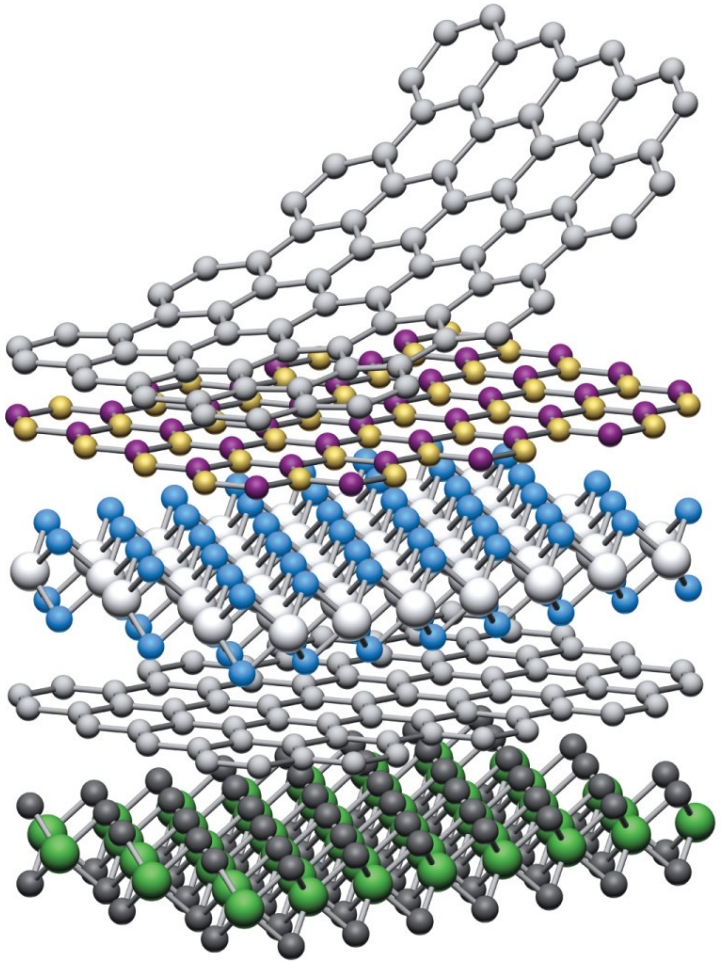
“Exfoliation”

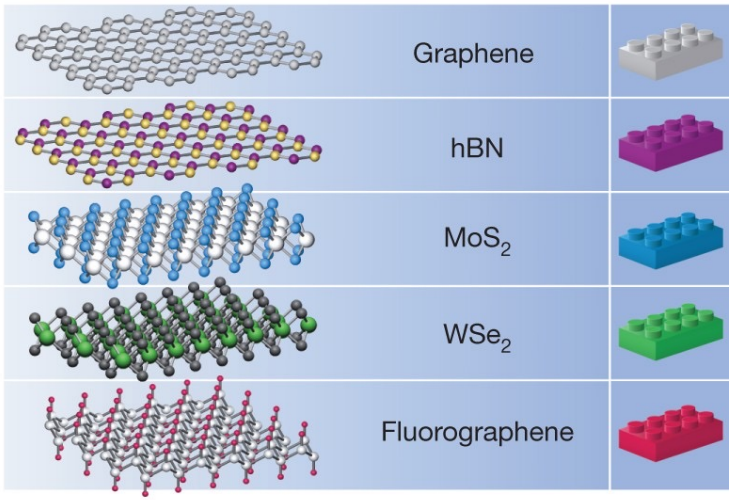


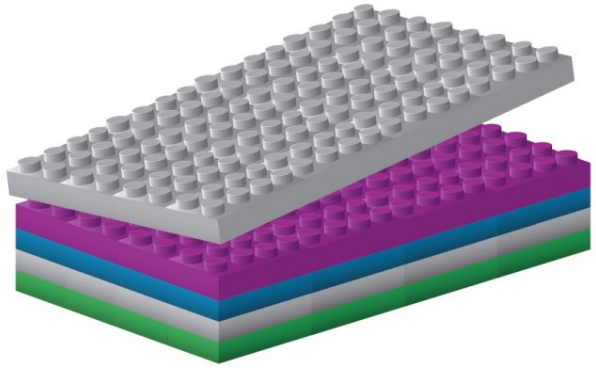


Nanowerk.com

Atomic LEGO blocks



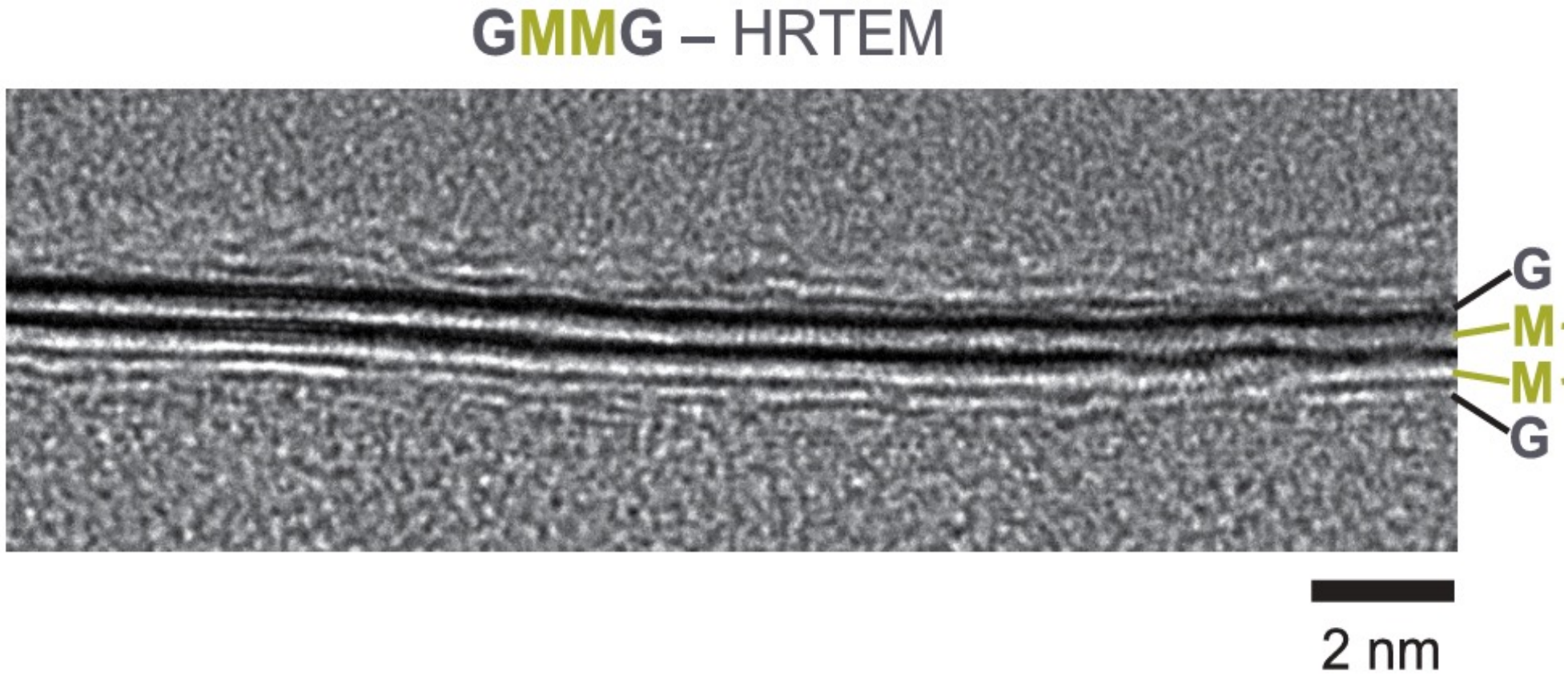




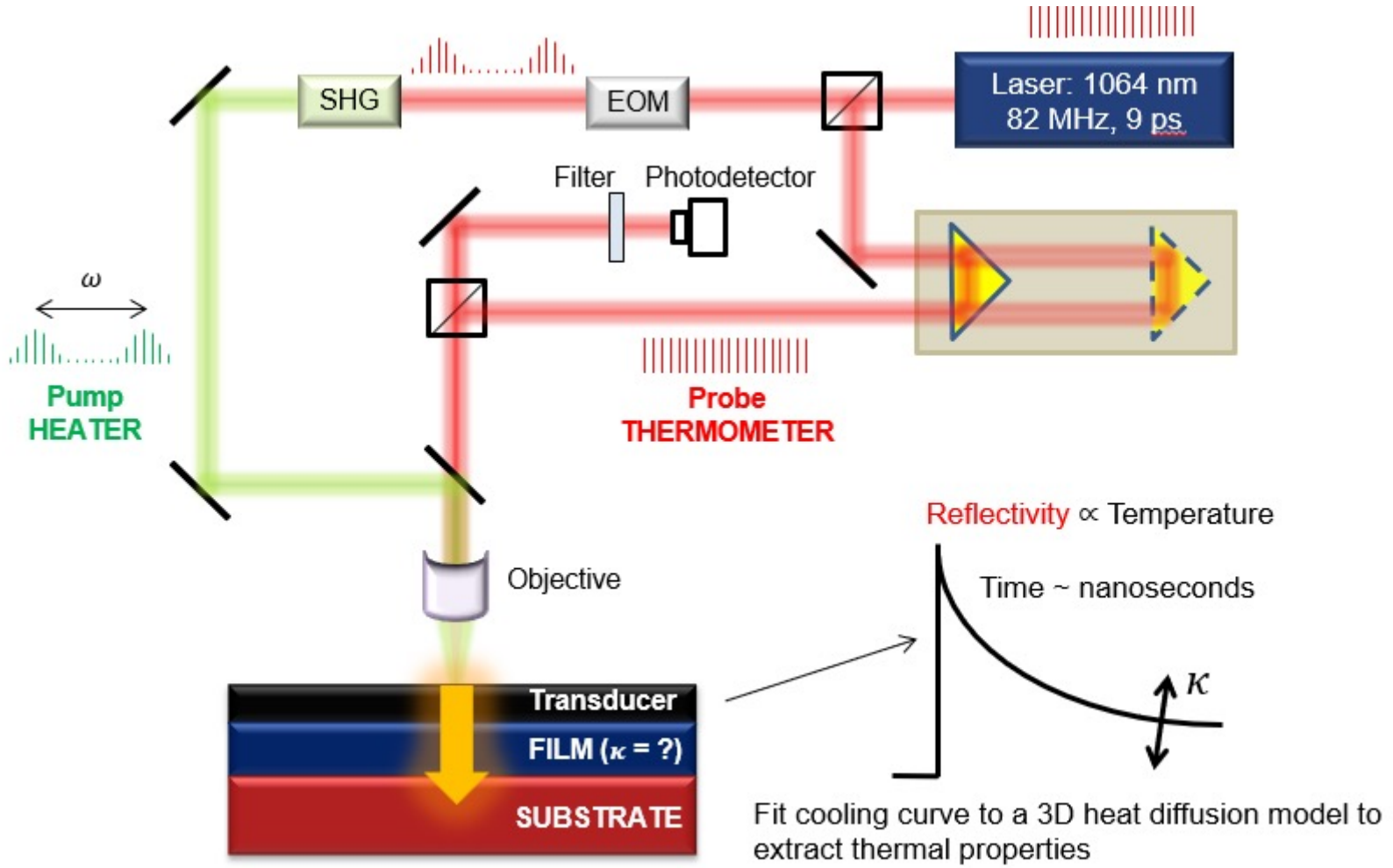
Geim and Grigorieva, Nature (2013)

Does this actually work?

- YES! Atomic-scale picture of an atomic sandwich

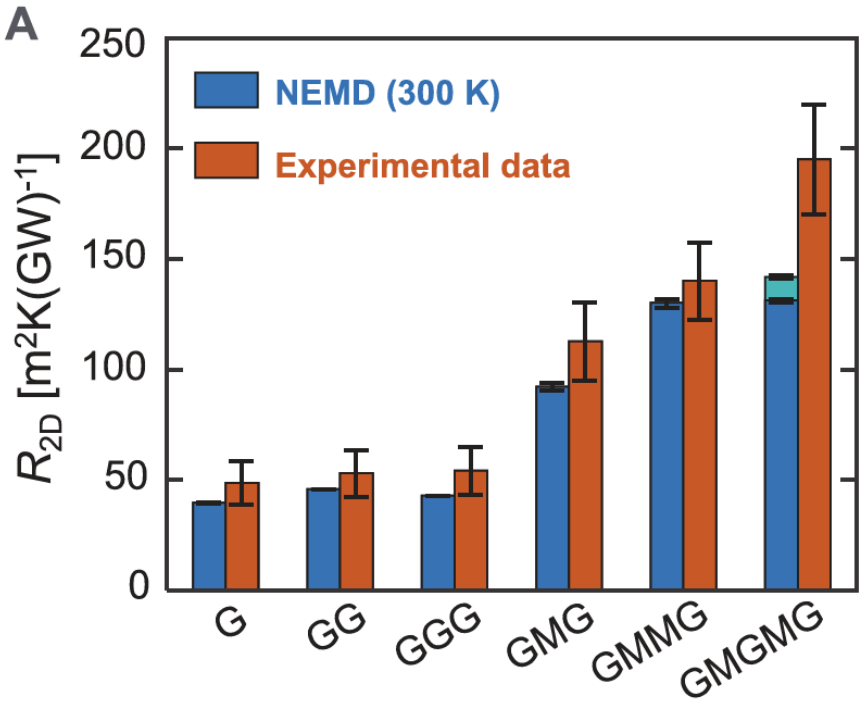


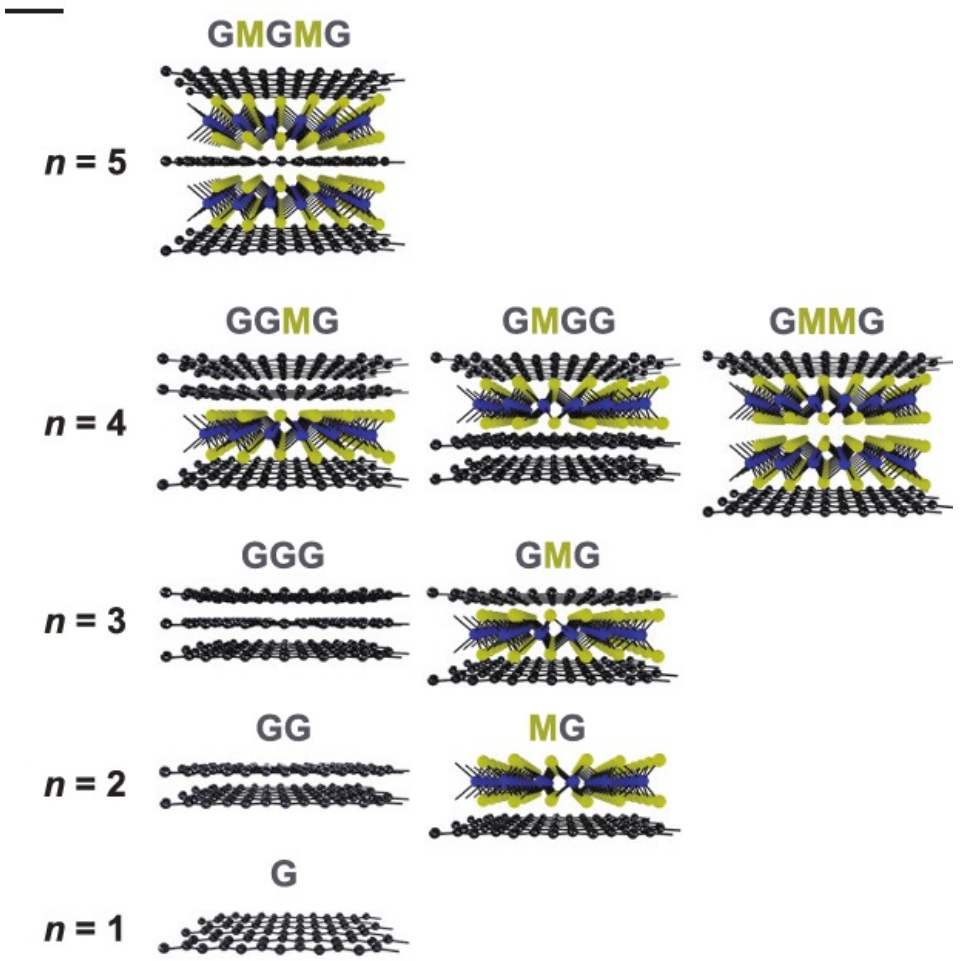
How we measure thermal properties at the atomic scale



Does this actually work?

- YES!





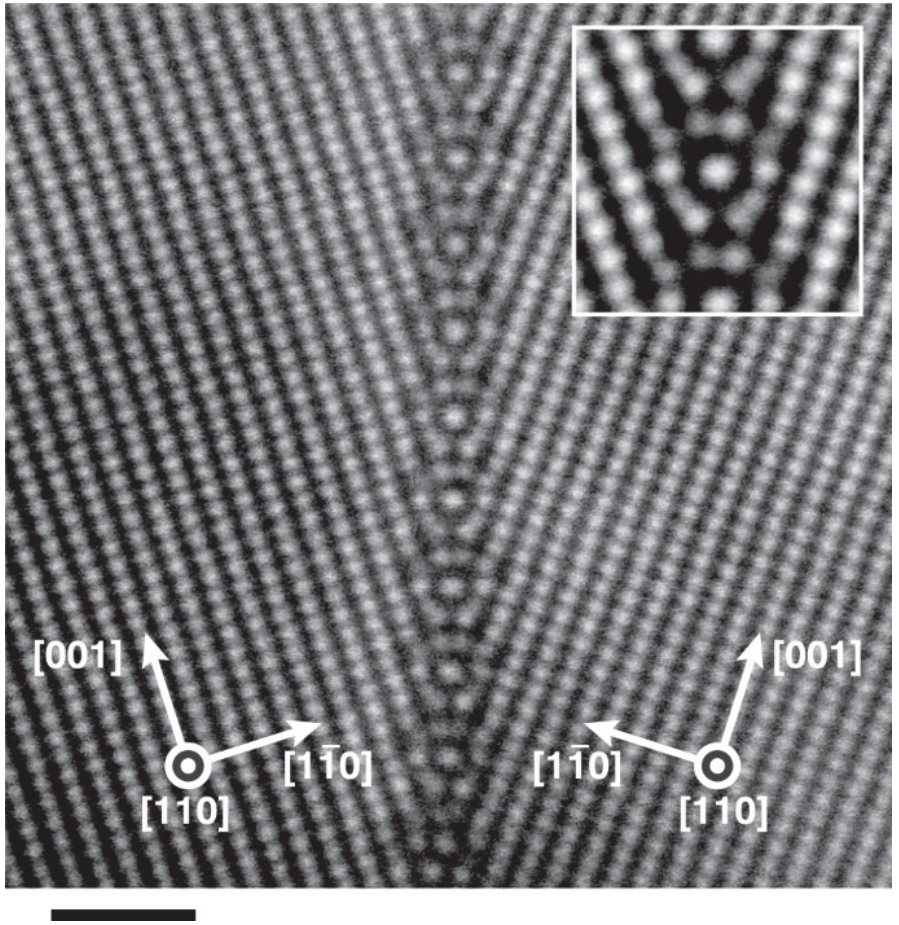
Thermal conductivity measured to be ~0.02 $Wm^{-1}K^{-1}$: LOWER THAN AIR!!

2. Good thermal conductors

Often, we don't want to block heat, but conduct it away quickly before something heats up. E.g. in the engine block

Need:
Really good thermal conductors

Challenge:
Most real materials have defects



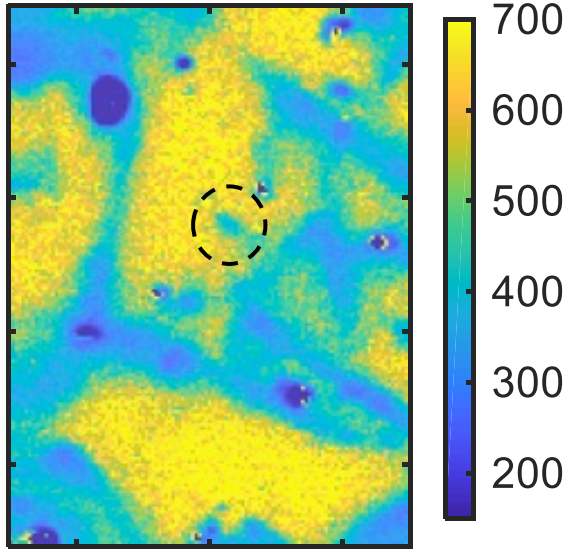
Seki et al., Nat Comm (2023)

Seeing is believing: how defects block heat

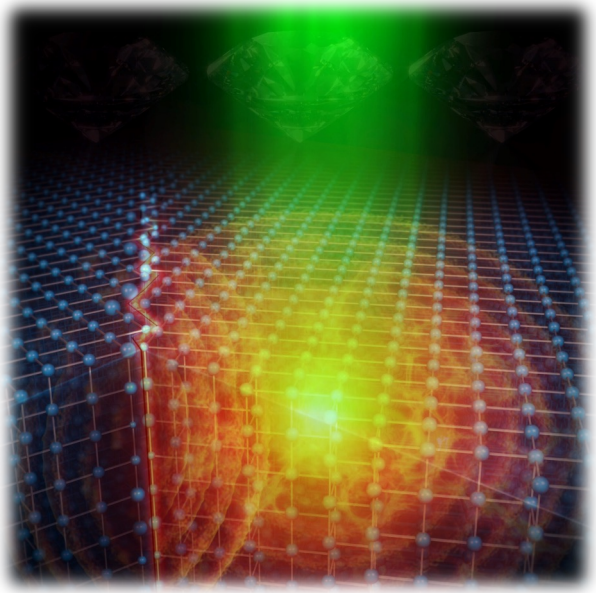
Grain structure

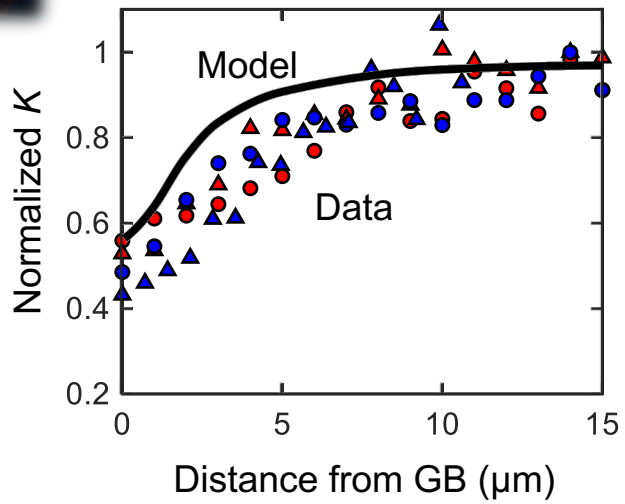
20 μm

Thermal conductivity [$Wm^{-1}K^{-1}$]



20 μm

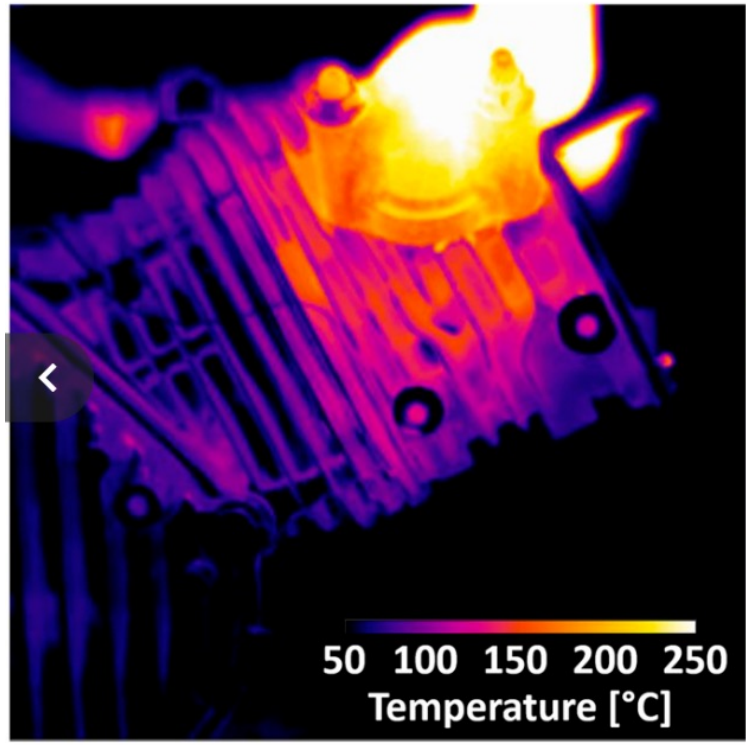


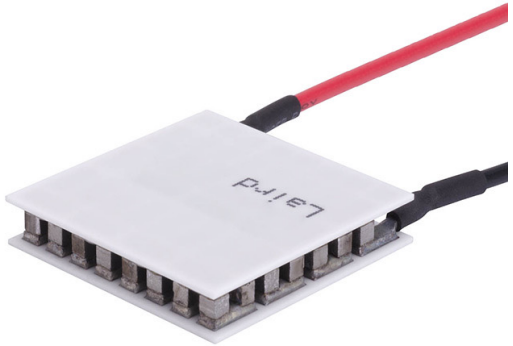


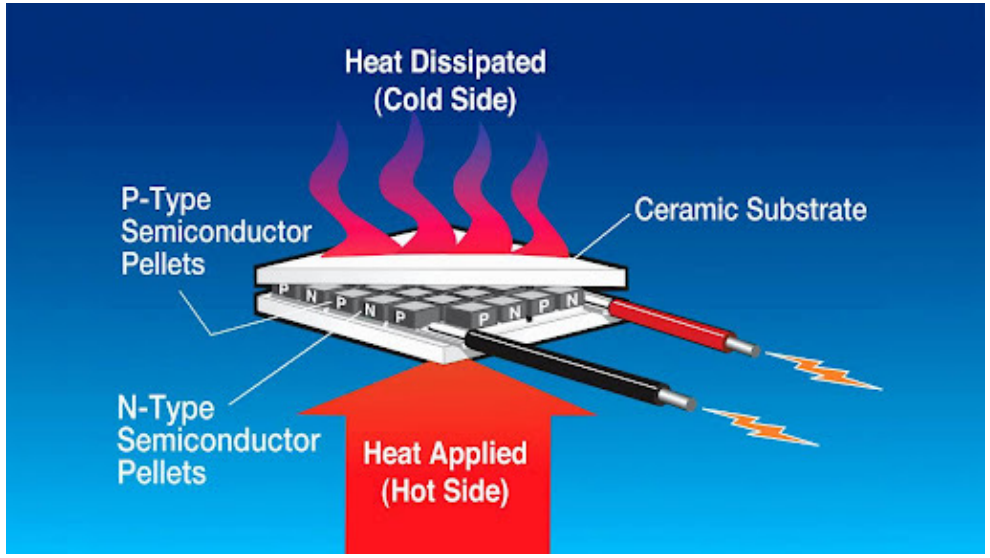
Sood et al., Nano Lett (2019)

3. Waste heat recovery → generate electricity

Thermoelectric materials: recover waste heat. **Fully solid-state!**



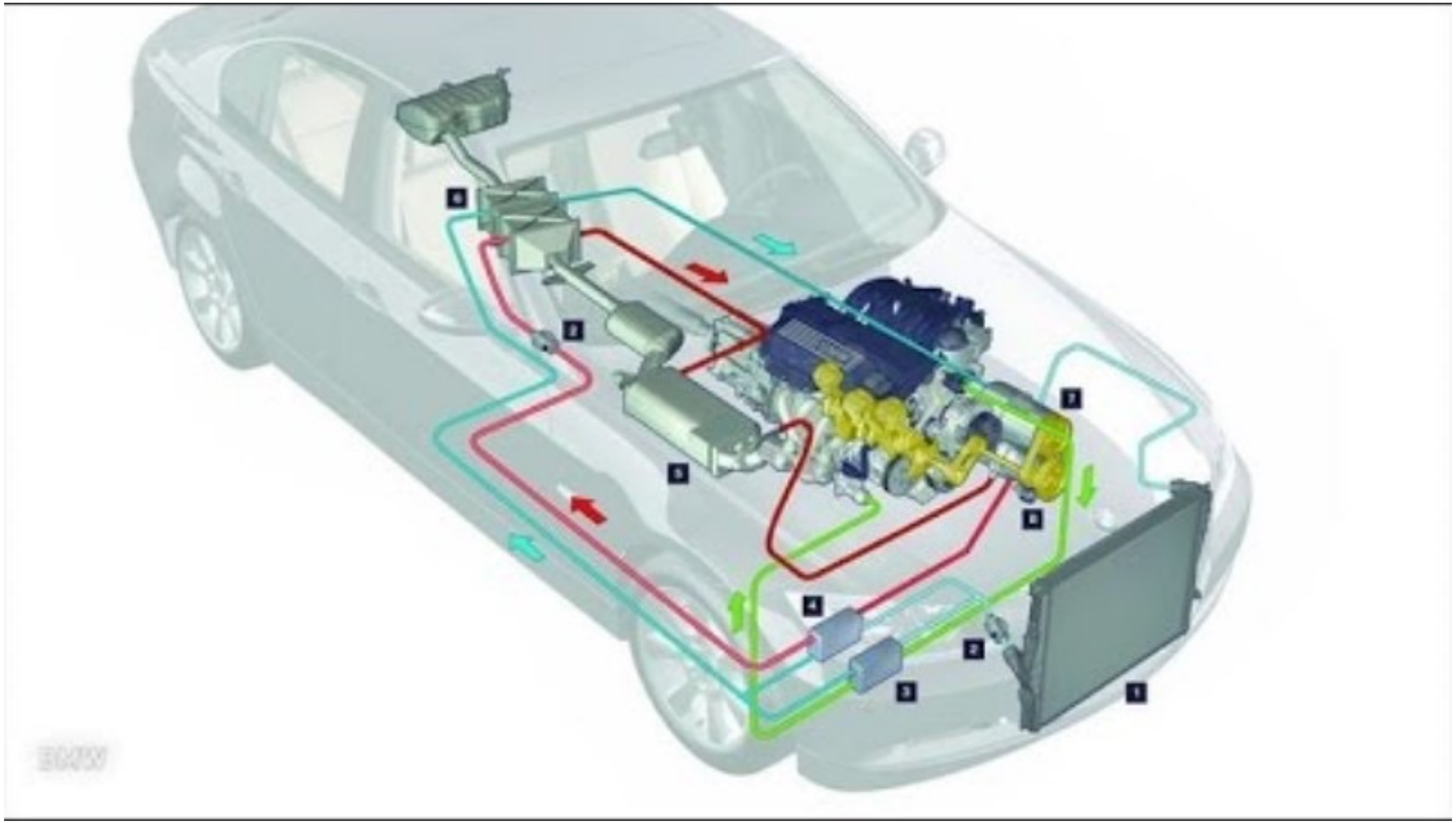




Conversion efficiency: $zT = \frac{S^2\sigma}{\kappa}$

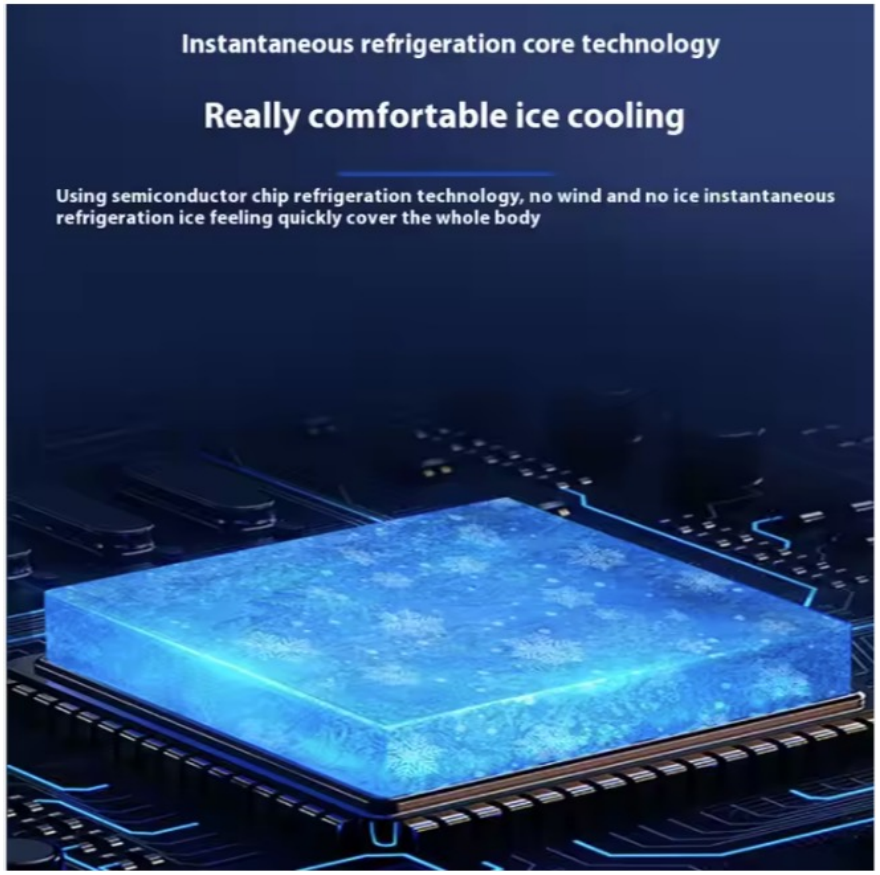
Wissink et al., PNAS (2020)

digikey



https://youtu.be/FChXGlt-WAM?si=6Qt9aPalyBcDzRgf

Or run this in reverse: a ‘cool’ motorcycle jacket



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