

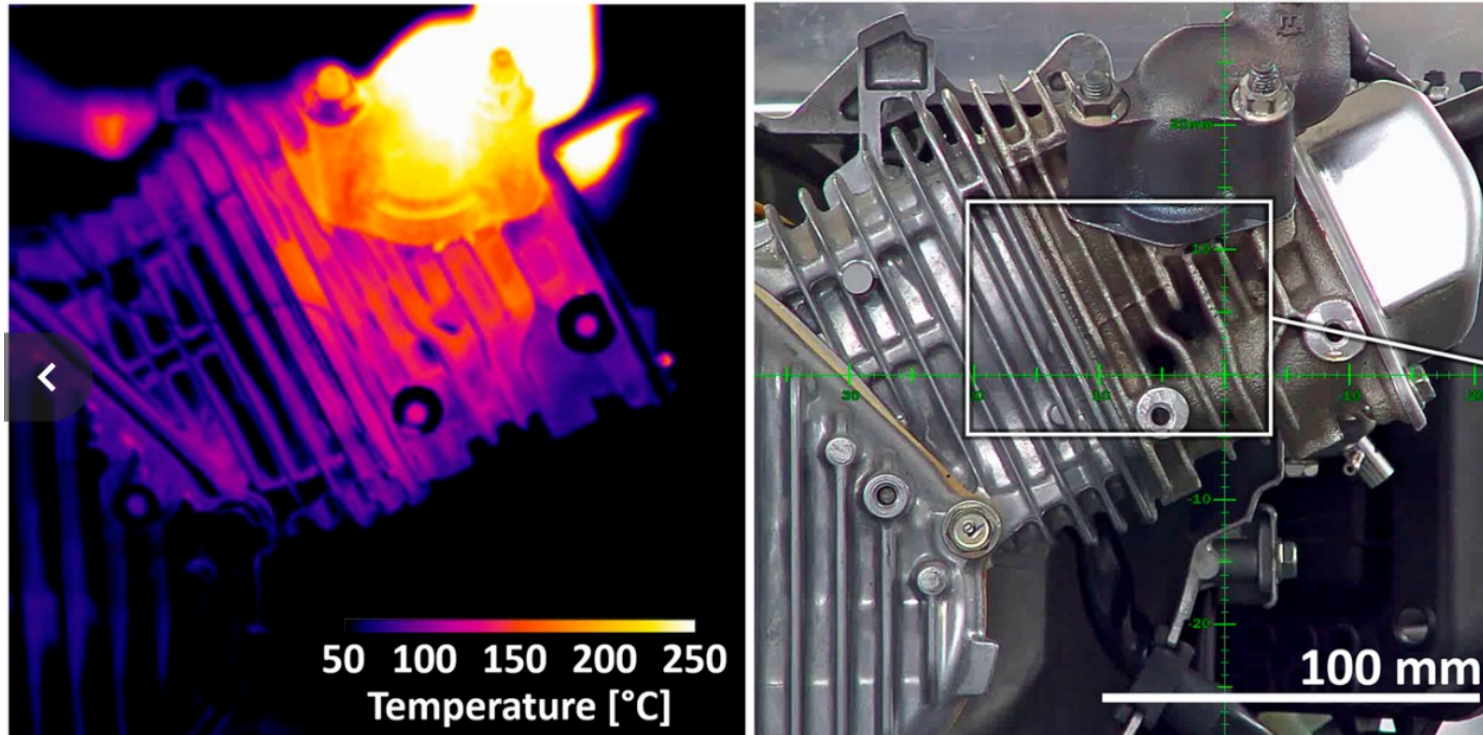
# Nanometers to Motorcycles

## Heat transfer across scales

Aditya Sood

Assistant Professor, MAE & PMI

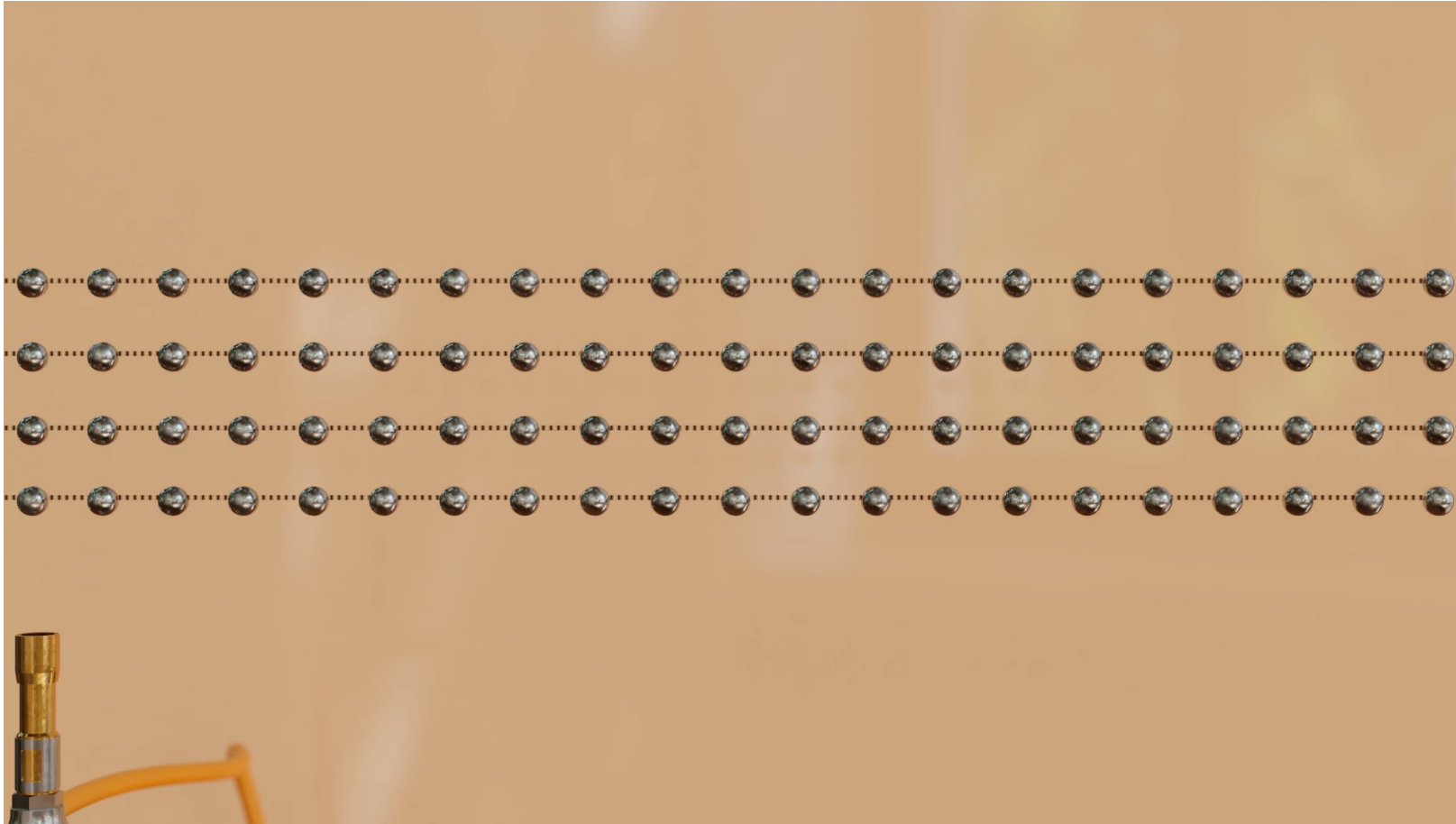
# Heat transfer matters in motorcycles



Wissink et al., PNAS (2020)

- Extreme temperatures in the combustion chamber: gases can get as hot as  $\sim 2,200$  C!
- Leads to high temperatures in the engine block  $\rightarrow$  heat transfer to chassis  
critical for: safety, mechanical integrity, comfort

# Zoom into the nanoscale: what is heat?



# “phonons”

Really high frequency atomic vibrations that  
carry heat in electrical insulators

# How is heat conducted in metals?



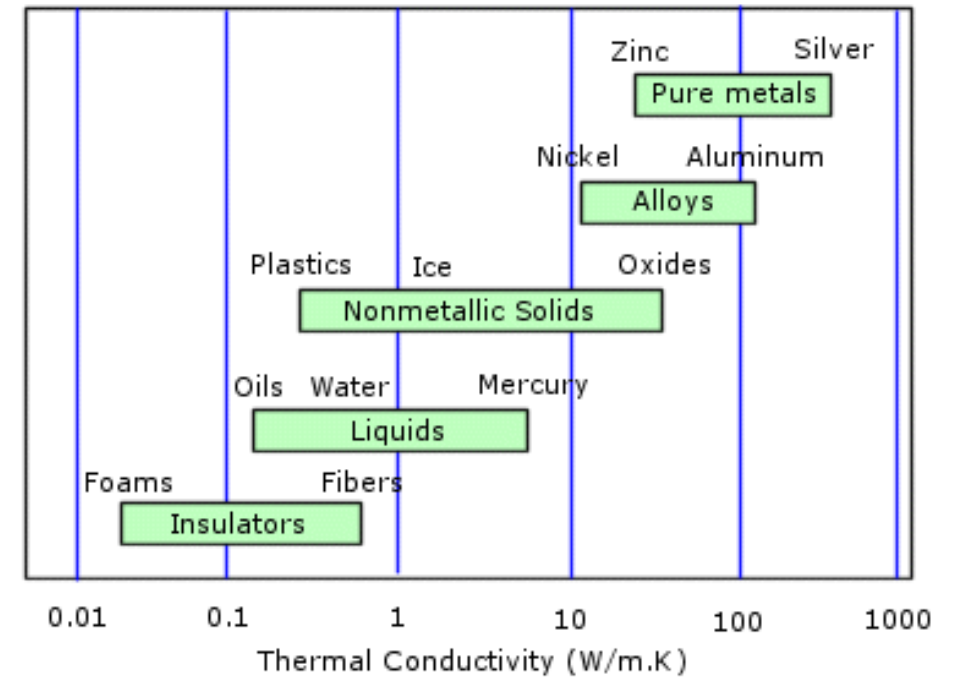
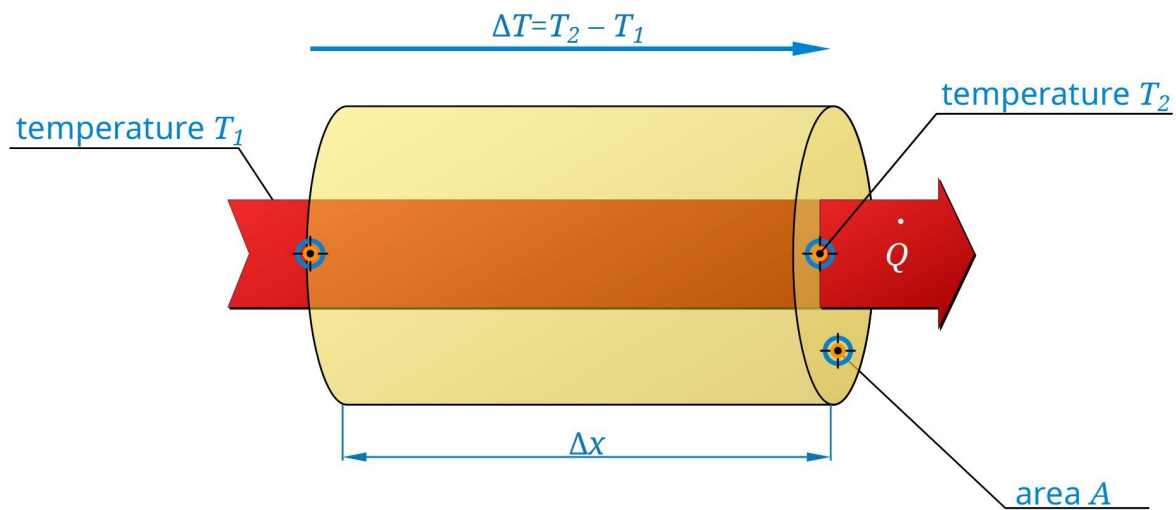
# electrons

Charges carry heat (and electricity!) in metals

# Bulk vs nanoscale: heat conduction

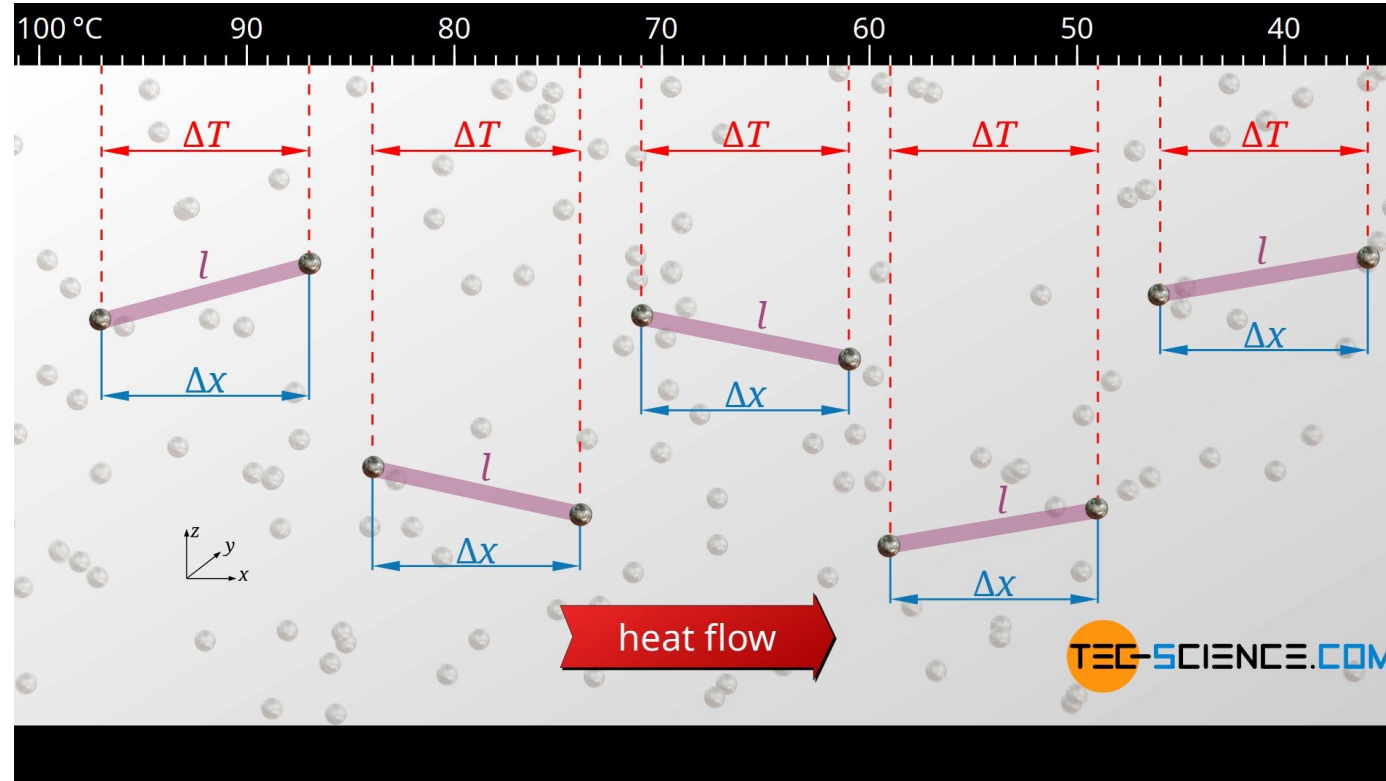
- Bulk: Fourier Law

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



# Bulk vs nanoscale: heat conduction

- But this breaks down for nanoscale materials!



# 1. Thermal barrier coatings

Piston crown



**Need:**

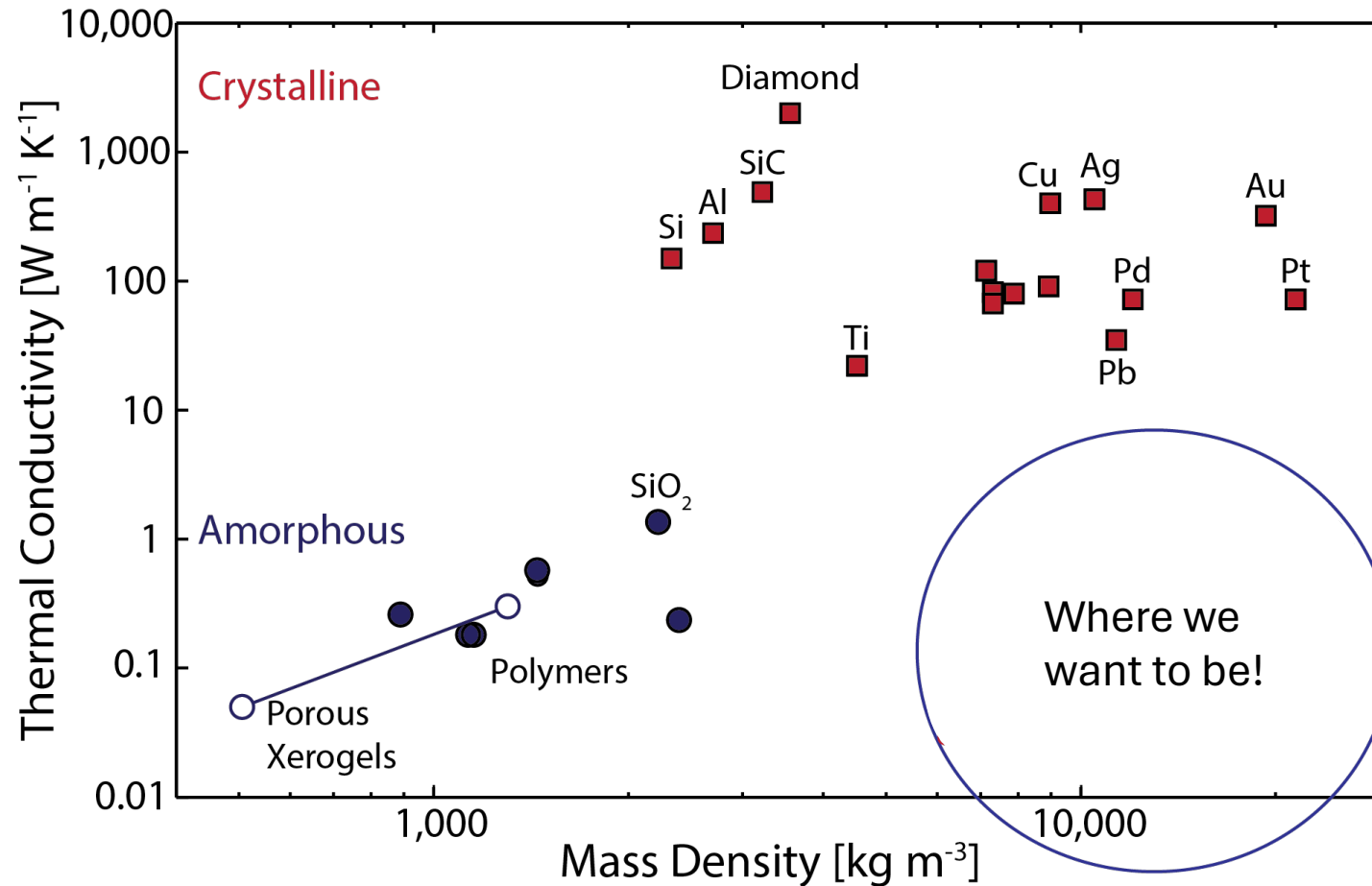
**Mechanically rigid (dense) thermal insulators**

Must insulate the piston from the hot combusting gases!

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



# This is not easy! Materials design challenge

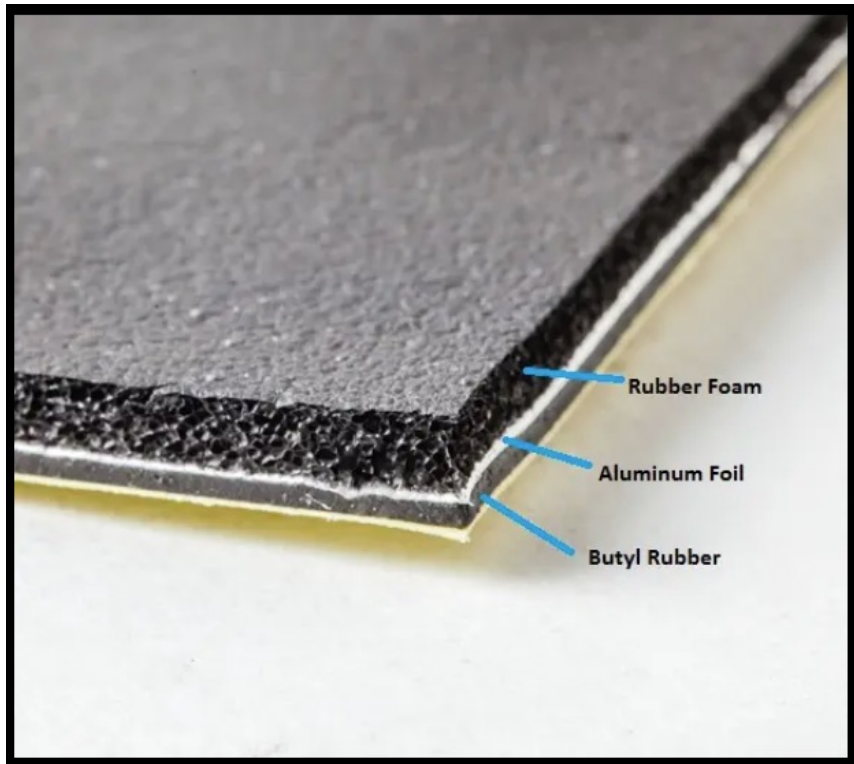


Barako, PhD dissertation  
Stanford University

- Most thermal insulators are mechanically soft – bad!

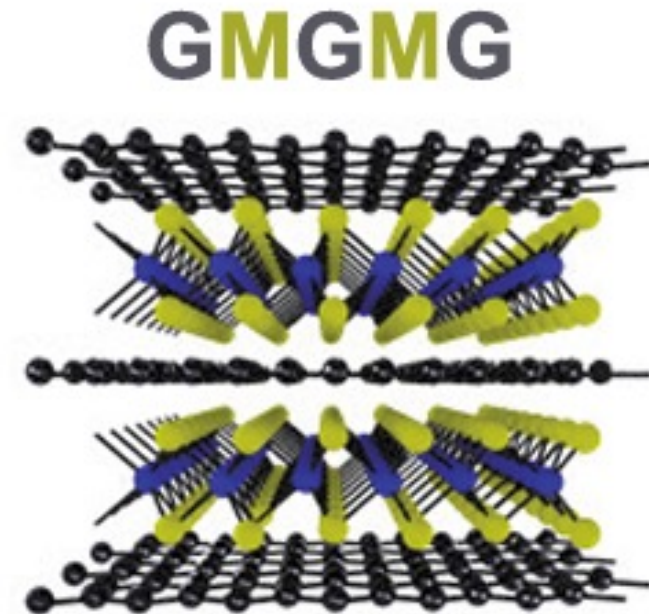
# Inspiration from acoustics

- Multilayers block sound:  
acoustic impedance



Alibaba.com

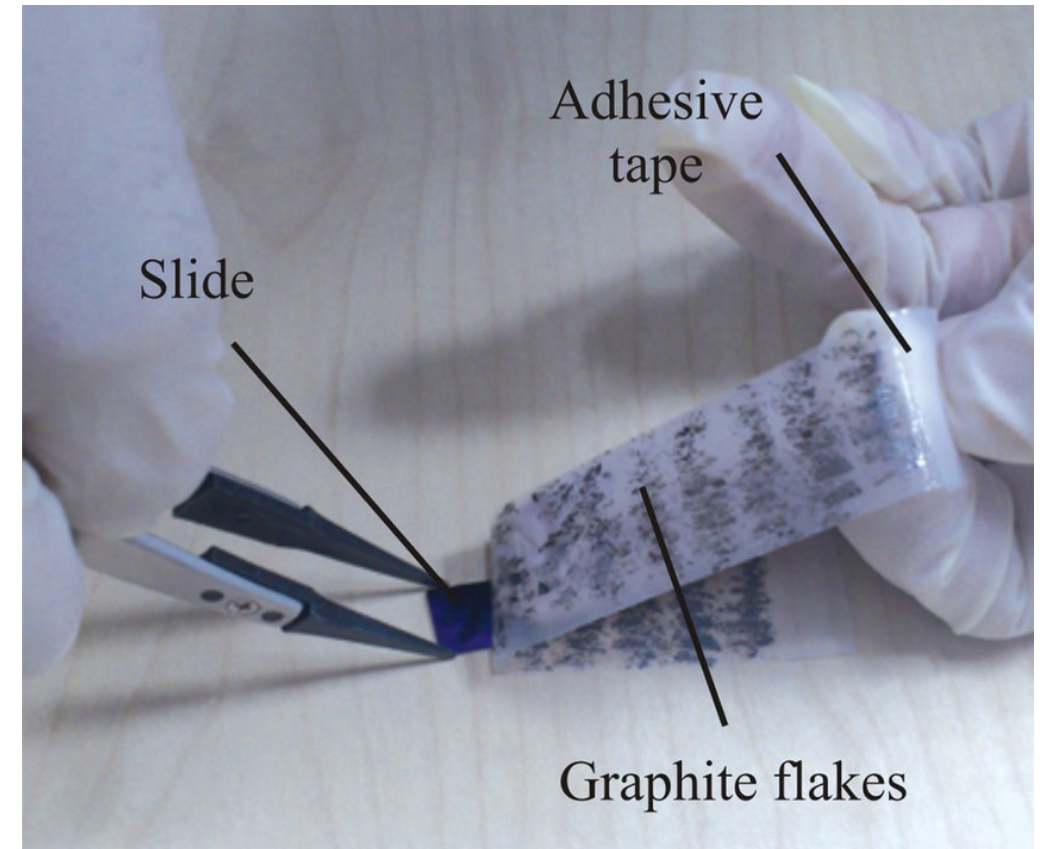
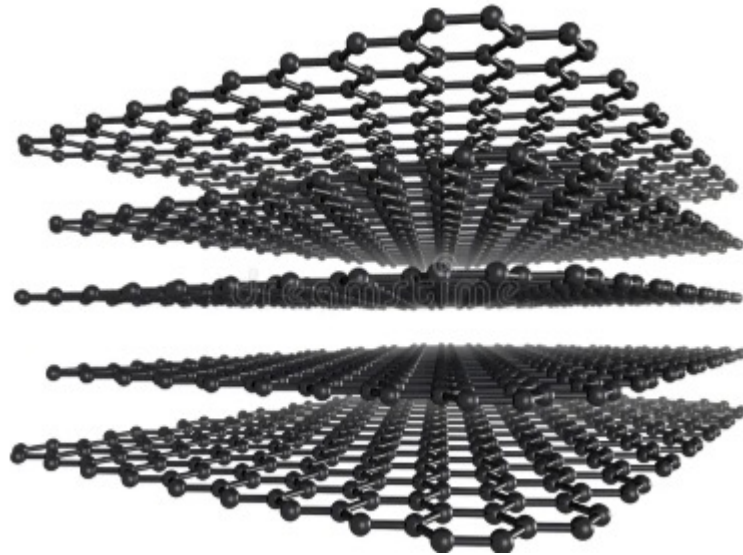
- Extend this idea to the atom scale!
- Alternate light and heavy atoms



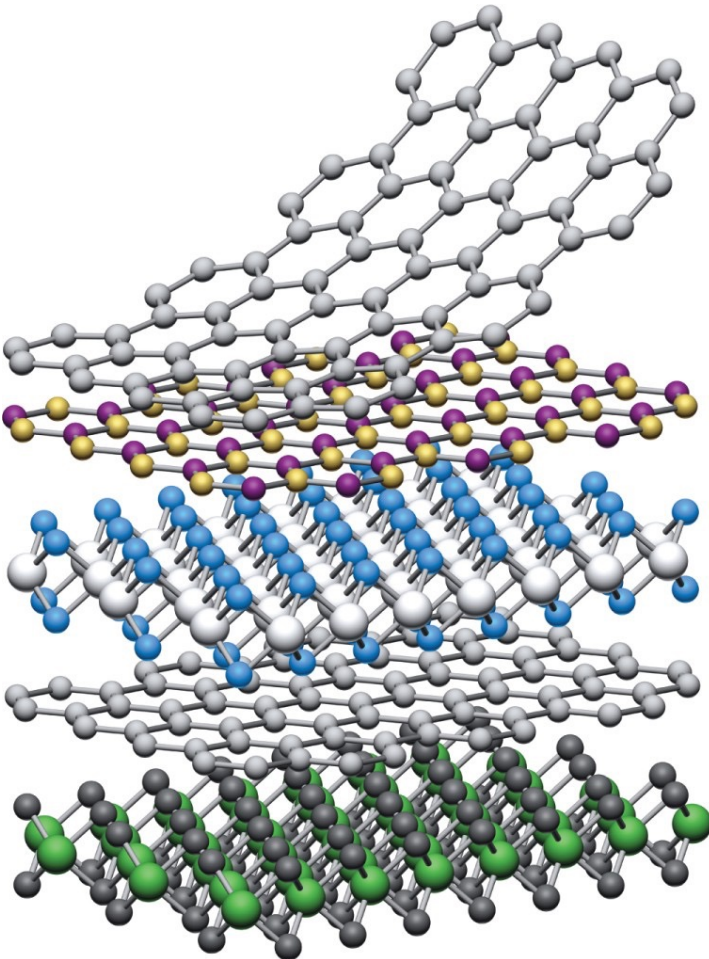
Sood et al., ACS Nano (2021)

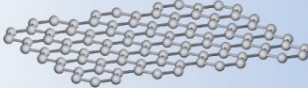

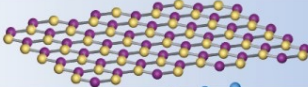

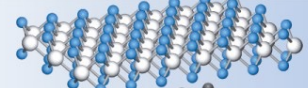

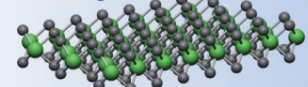

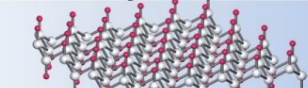

# Fascinating world of 2D materials

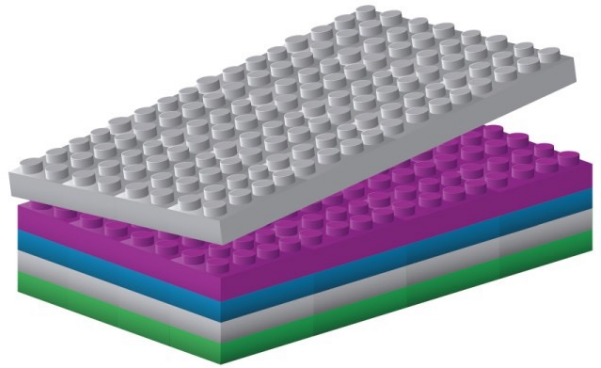
“Exfoliation”



# Atomic LEGO blocks



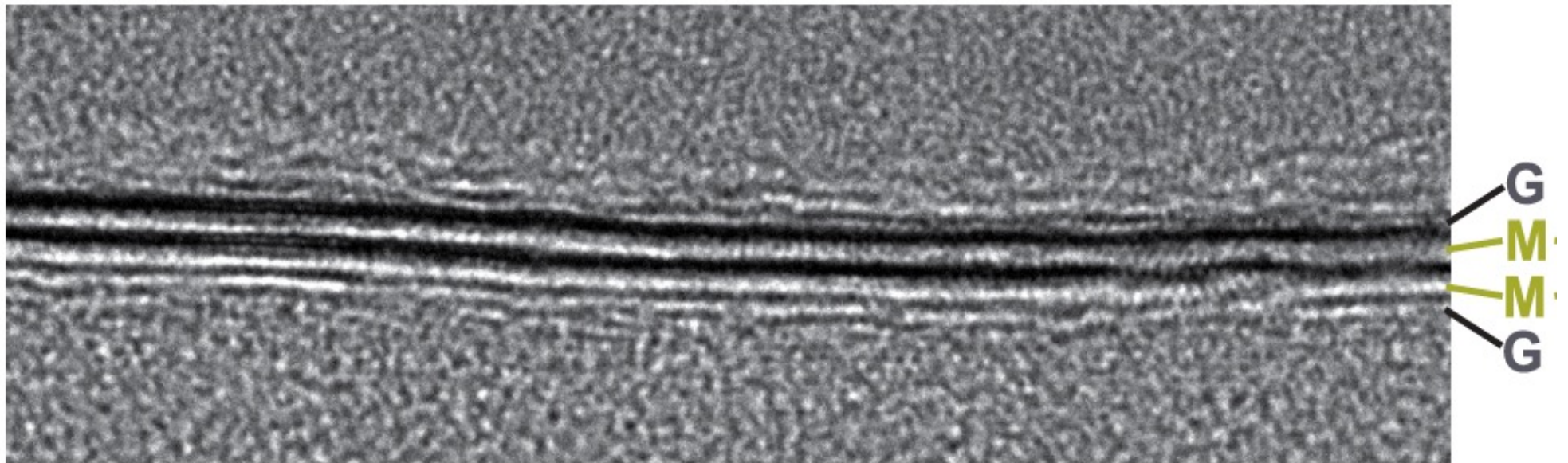
	Graphene	
	hBN	
	MoS <sub>2</sub>	
	WSe <sub>2</sub>	
	Fluorographene	



# Does this actually work?

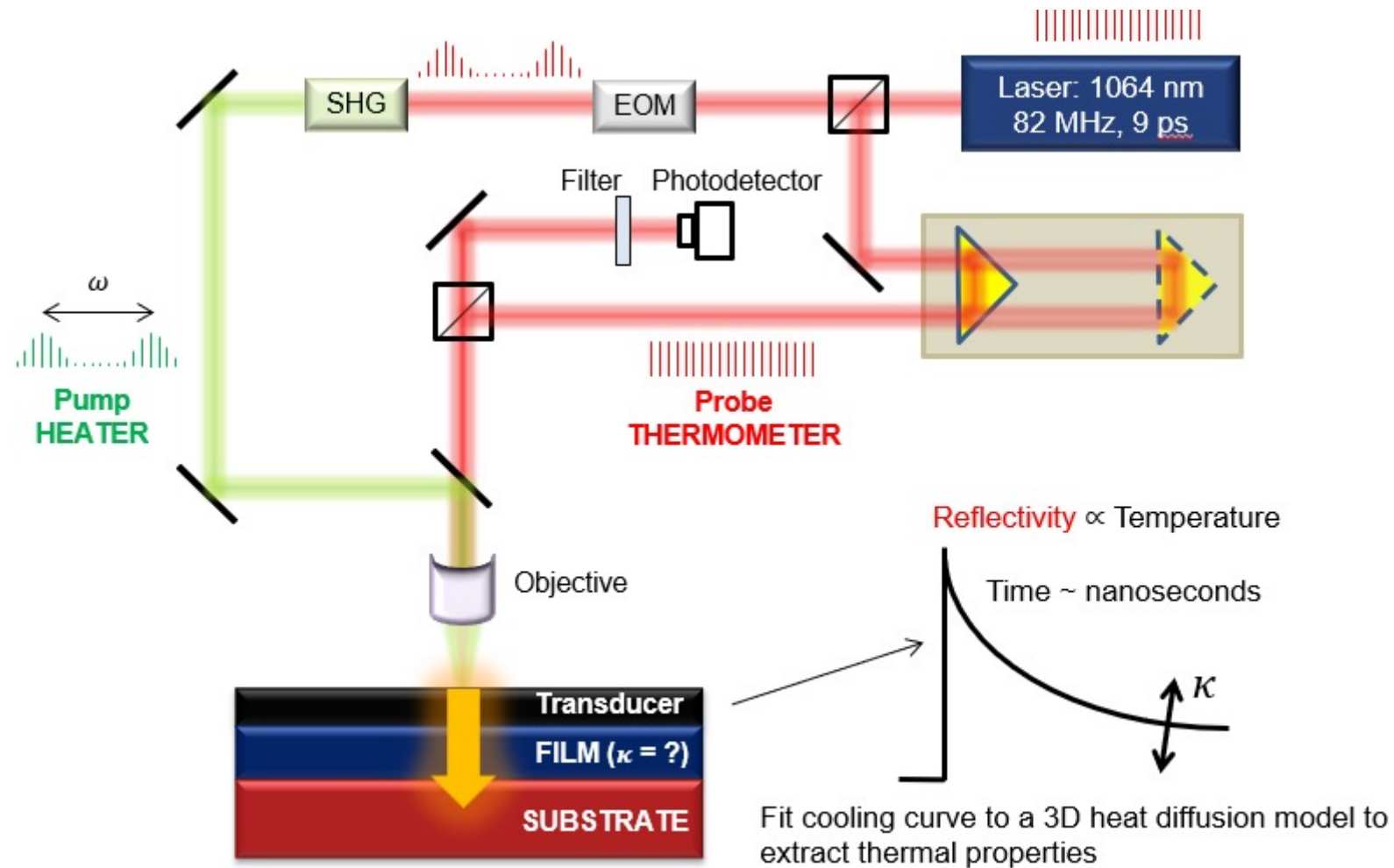
- YES! Atomic-scale picture of an atomic sandwich

**GMMG** – HRTEM



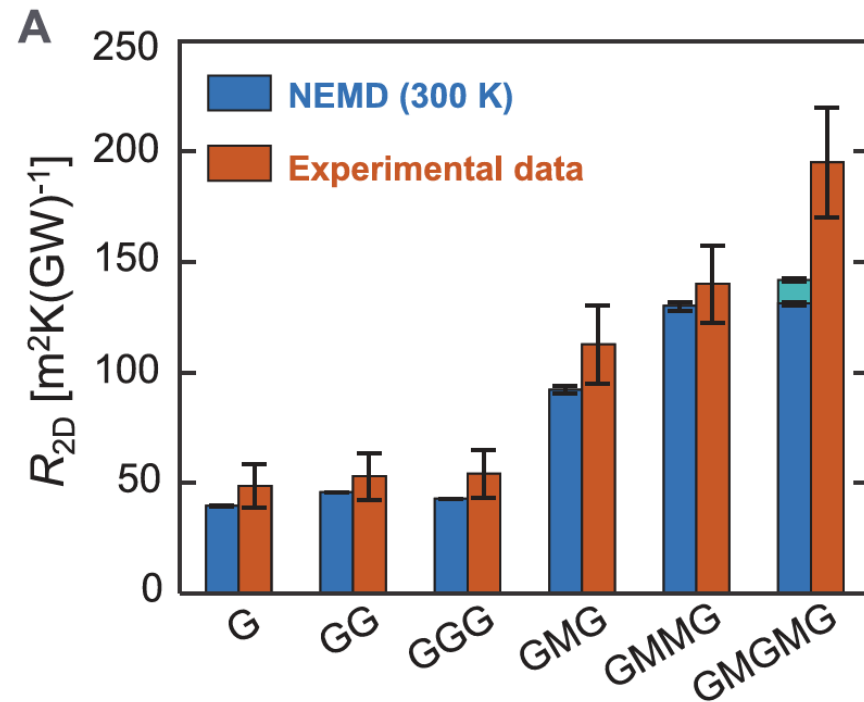
2 nm

# How we measure thermal properties at the atomic scale

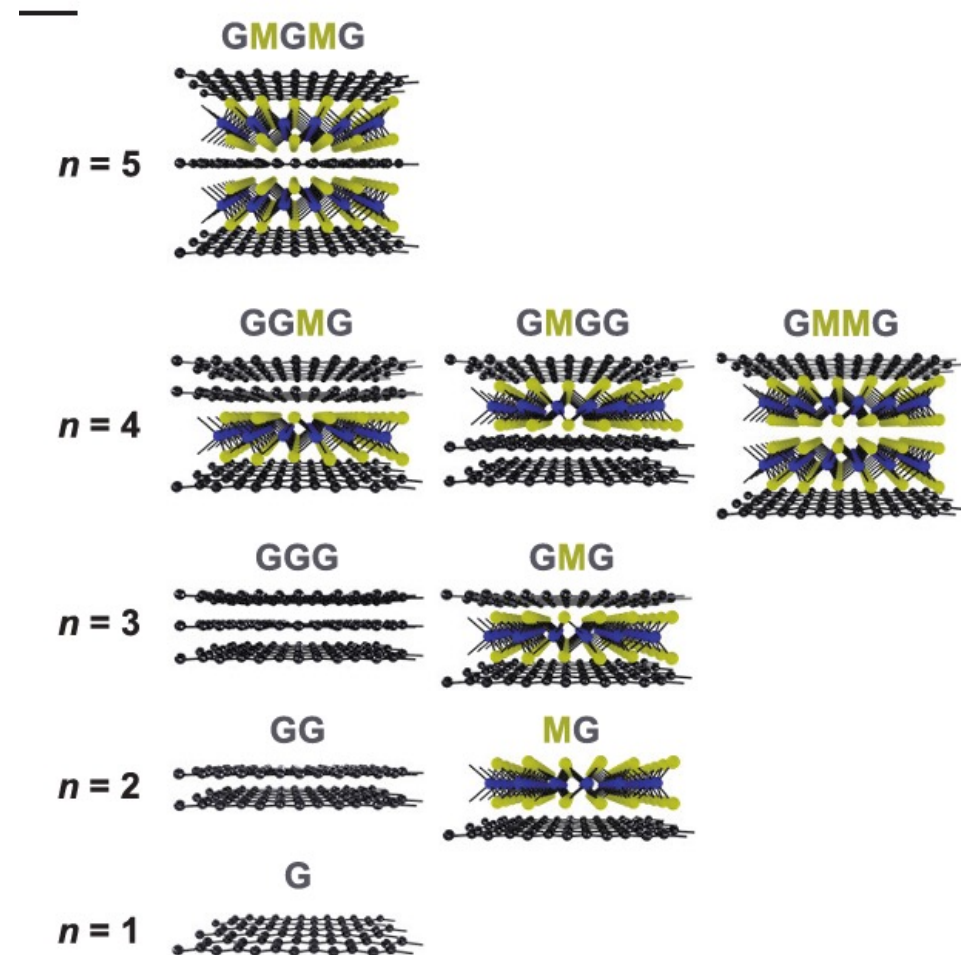


# Does this actually work?

- YES!



**Thermal conductivity measured to be  
~0.02 Wm<sup>-1</sup>K<sup>-1</sup> : LOWER THAN AIR!!**



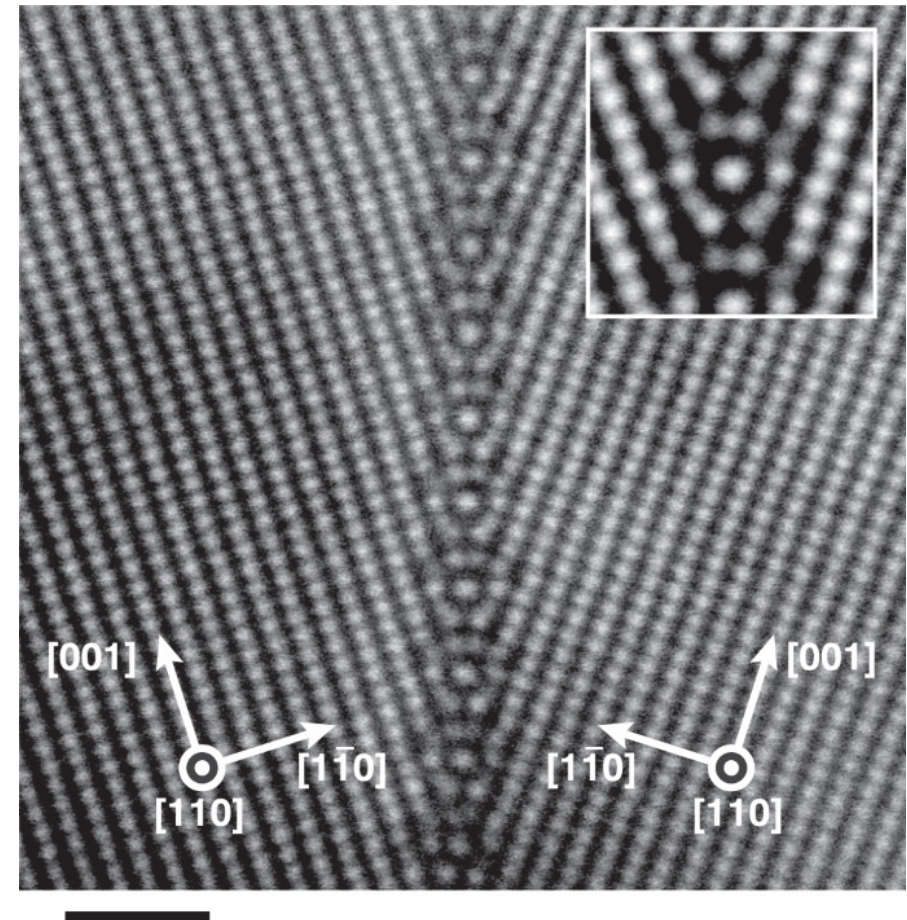
## 2. Good thermal conductors

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)



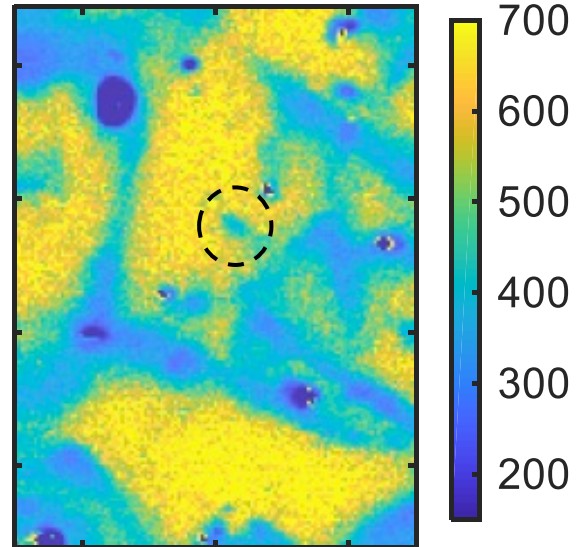
# Seeing is believing: how defects block heat

Grain structure

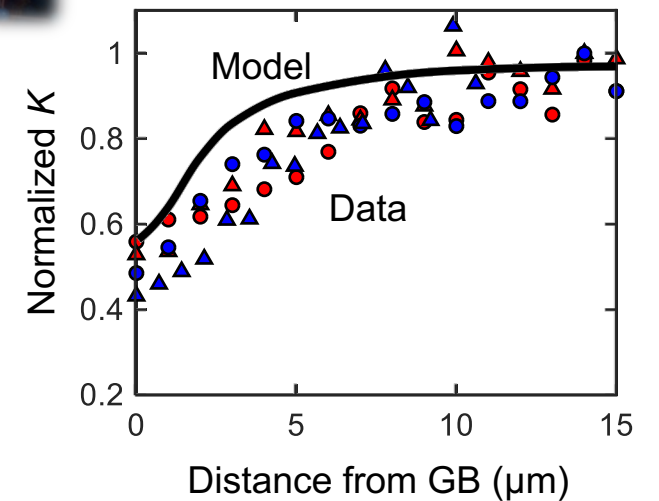
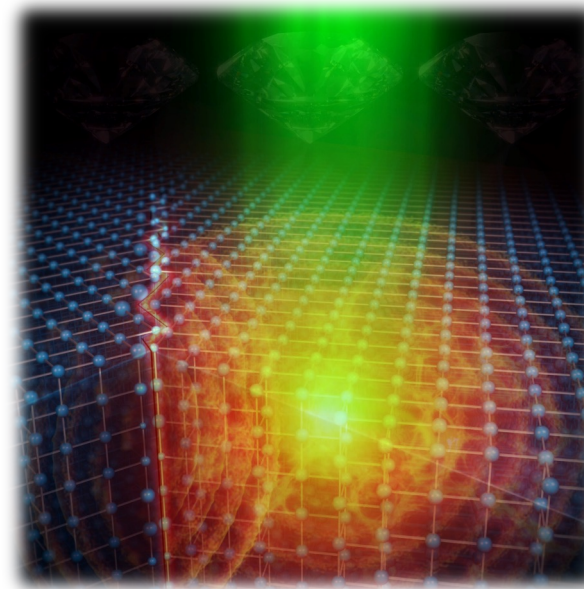


20 μm

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



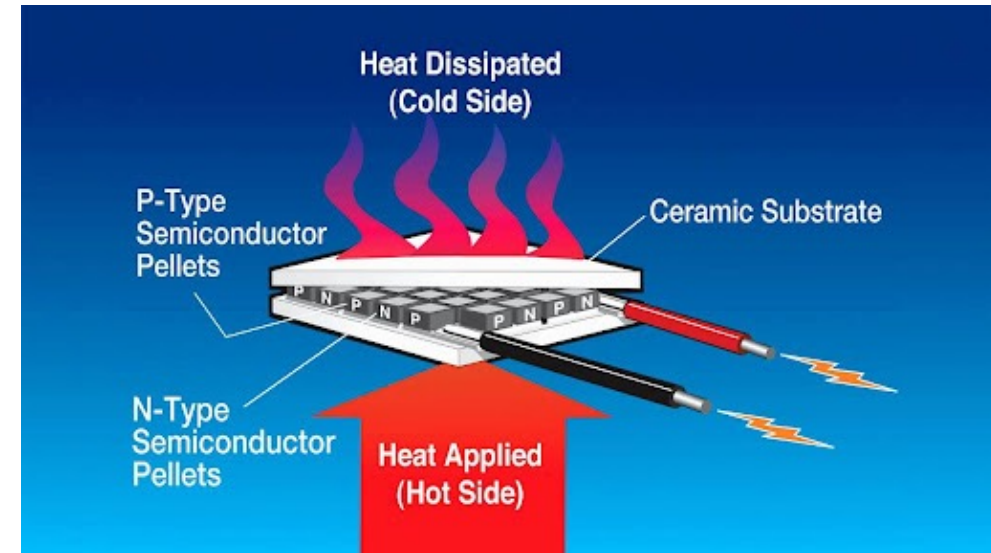
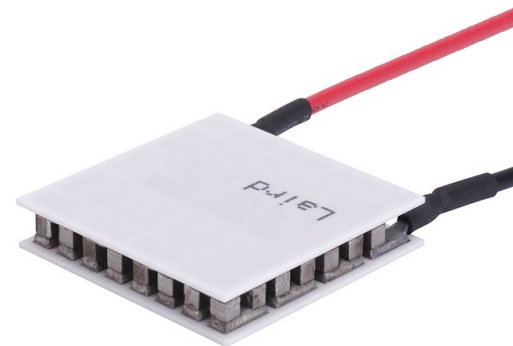
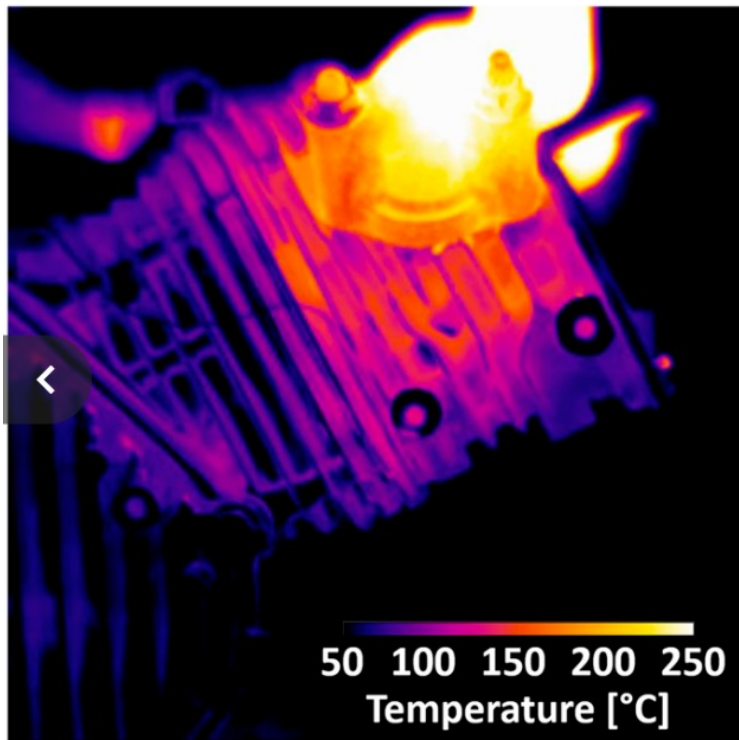
20 μm



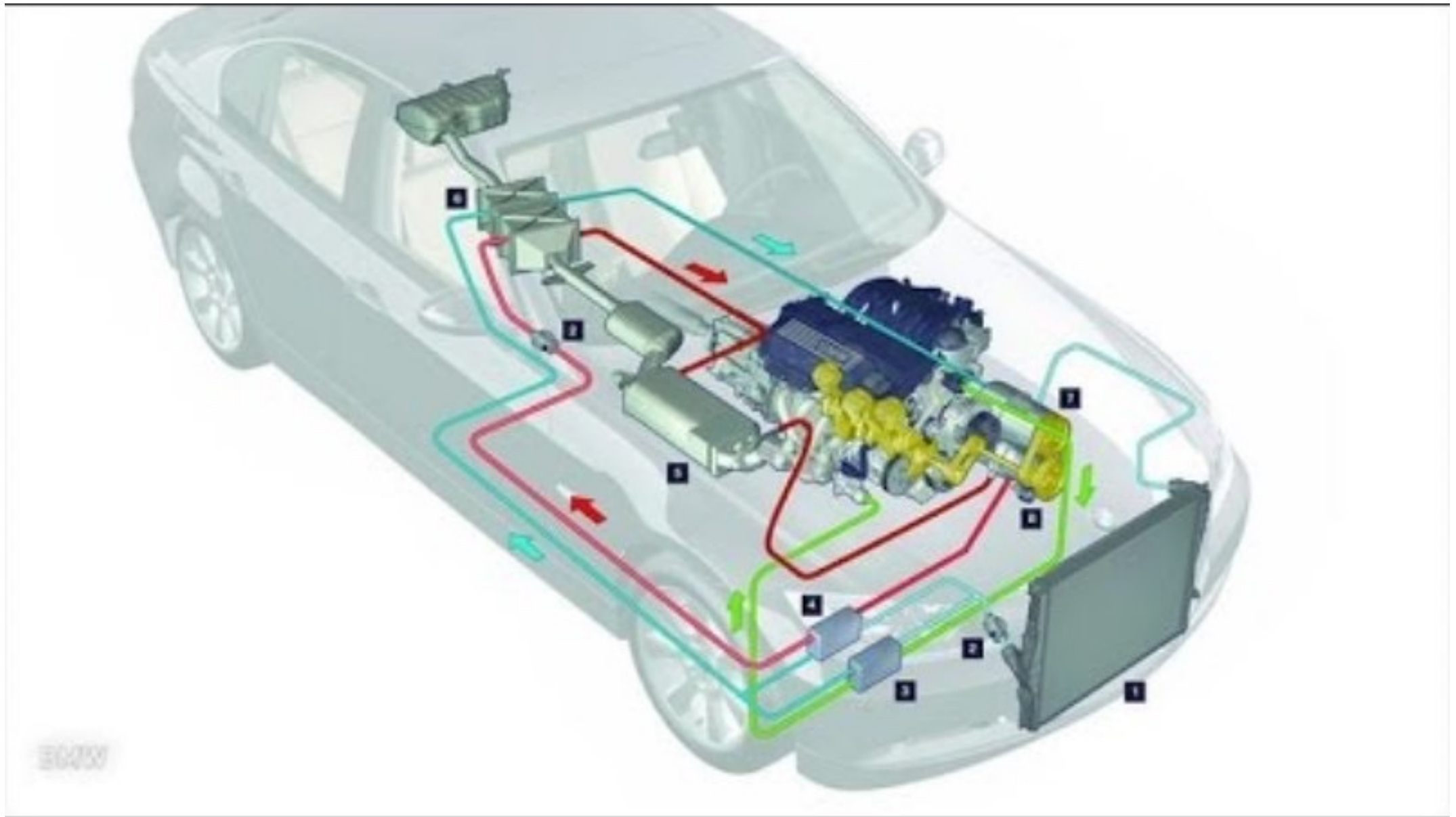
Sood et al., Nano Lett (2019)

### 3. Waste heat recovery → generate electricity

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



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



# Or run this in reverse: a 'cool' motorcycle jacket

**Core performance explosion**

**Rapid cooling of 15° C quickly stimulates ice sensation**

In high-temperature scenes, one-button refrigeration is turned on and the temperature drops by 15° C to deliver ice sensation to the human body, and the whole body can enjoy ice coolness.



Alibaba.com

**Instantaneous refrigeration core technology**

**Really comfortable ice cooling**

Using semiconductor chip refrigeration technology, no wind and no ice instantaneous refrigeration ice feeling quickly cover the whole body



2025 High-Temperature Work Vest Peltier Semiconductor Refrigeration Cooling Sports Clothing Air Conditioning Fishing Safety Vest

No reviews yet



Shanghai ZiXi Technology Co., Ltd. · **Verified** Custom manufacturer · 9 yrs · CN