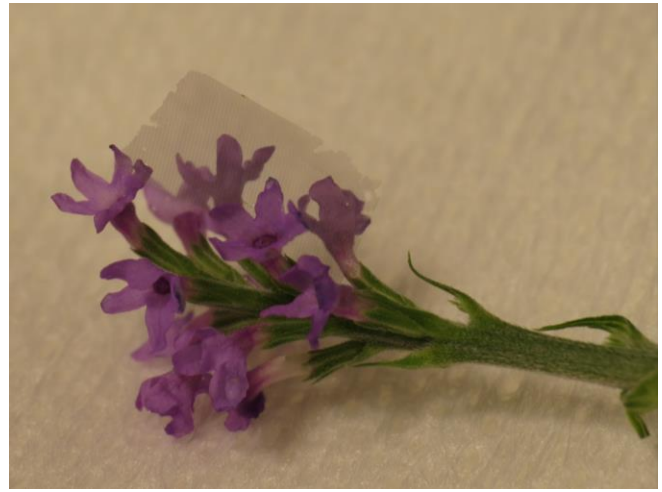
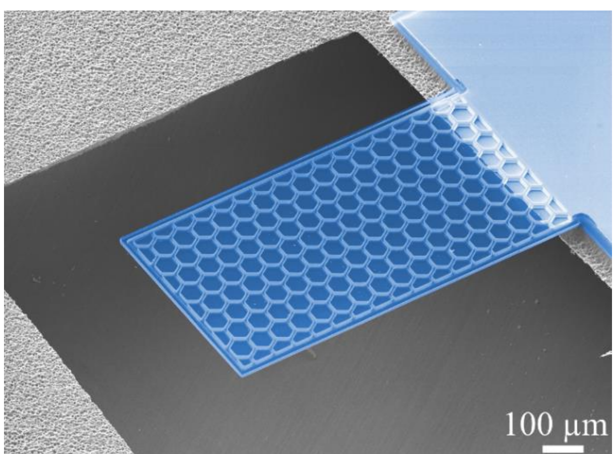



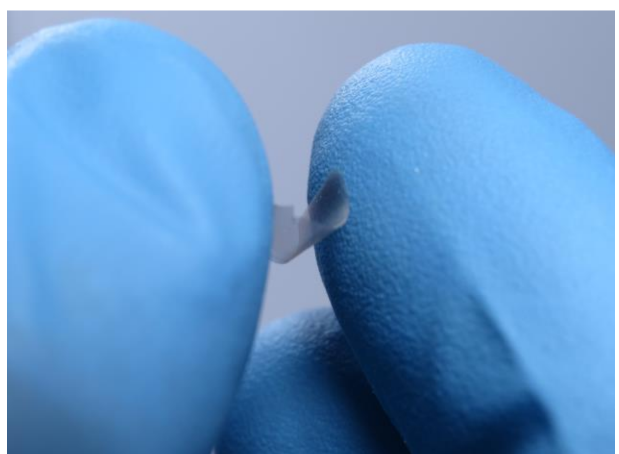
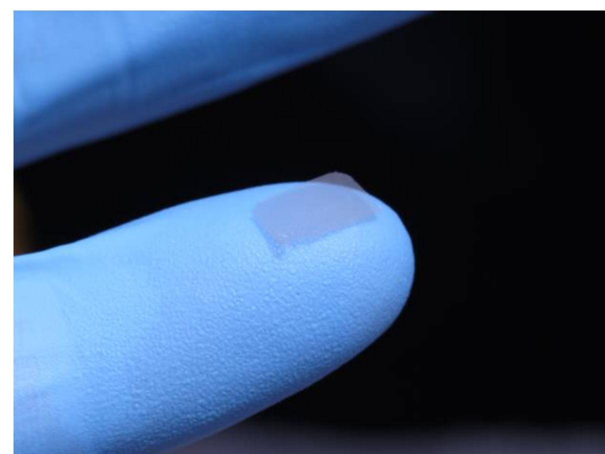
Ultrathin plates

Sam Nicaise

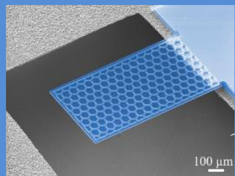
Y-Prize Tech Briefing

Oct 10, 2016

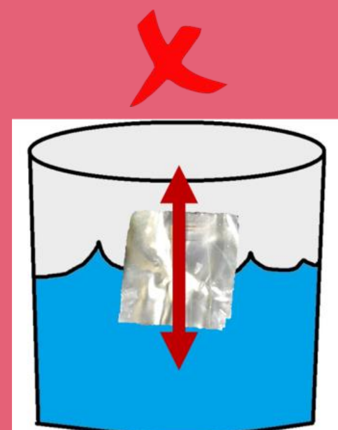


Beneficial Characteristics

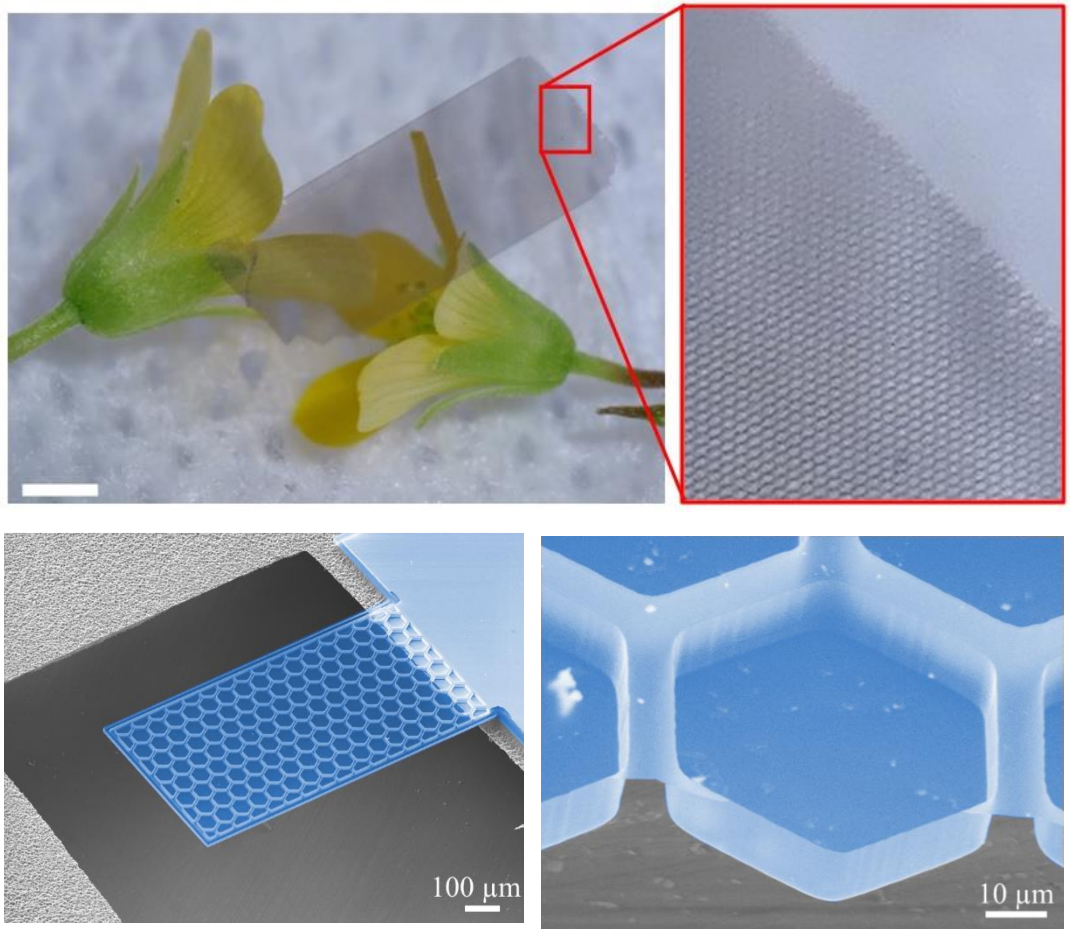


Technical Limitations



Ideas for Application

Ultrathin (25-100nm) continuous plates



Davami, Bargatin *et al.*, 2015, Nat. Commun. 6:10019 (2015)

Free- standing aluminum oxide (Al_2O_3) plates

- Only ~100 atoms thick (thousands of times thinner than paper, plastic cling wrap, or household aluminum foil)
- corrugated to increase their bending stiffness

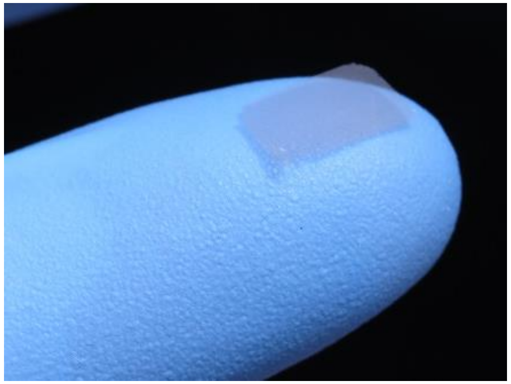
Everyday thicknesses

- 100 µm – sheet of paper
- 50 µm – human hair
- 3 µm – dia. of spider silk
- 0.025 - 0.1 µm – our structure

The thinnest macro-scale object

The thickness of soap films/bubbles is typically 0.1-1 micron, but can be less than 100 nm for a short period of time

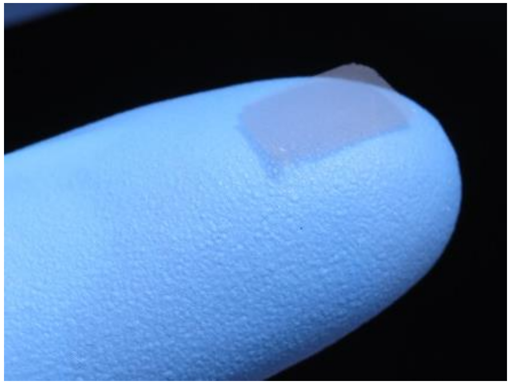
The previous macro-scale mechanical metamaterials were about 100 nm thick and had a framework (truss-like) structure



With 25-100 nm thickness and cm-scale length and width, these are the thinnest plates that can be picked up by hand

Bringing the nanoscale into the "real world"!

Ultra Light Weight



1 square centimeter

→ 10 - 100 micrograms!

How many times heavier?

Feathers: 1000-10000×

Bees:

3000-

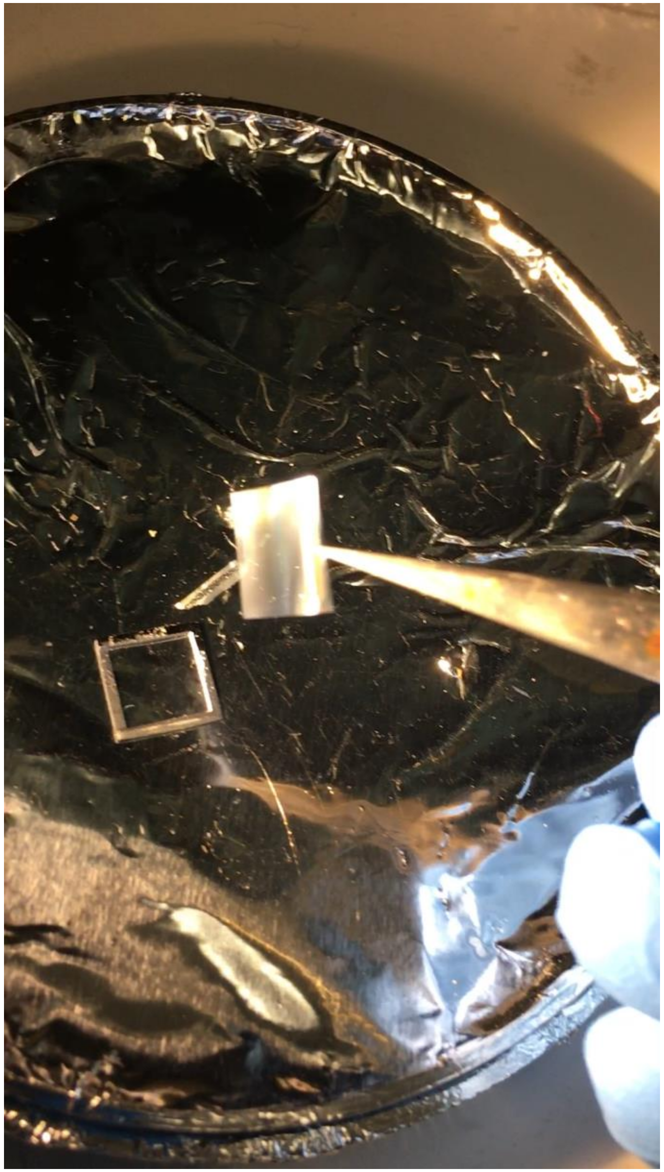
30000×

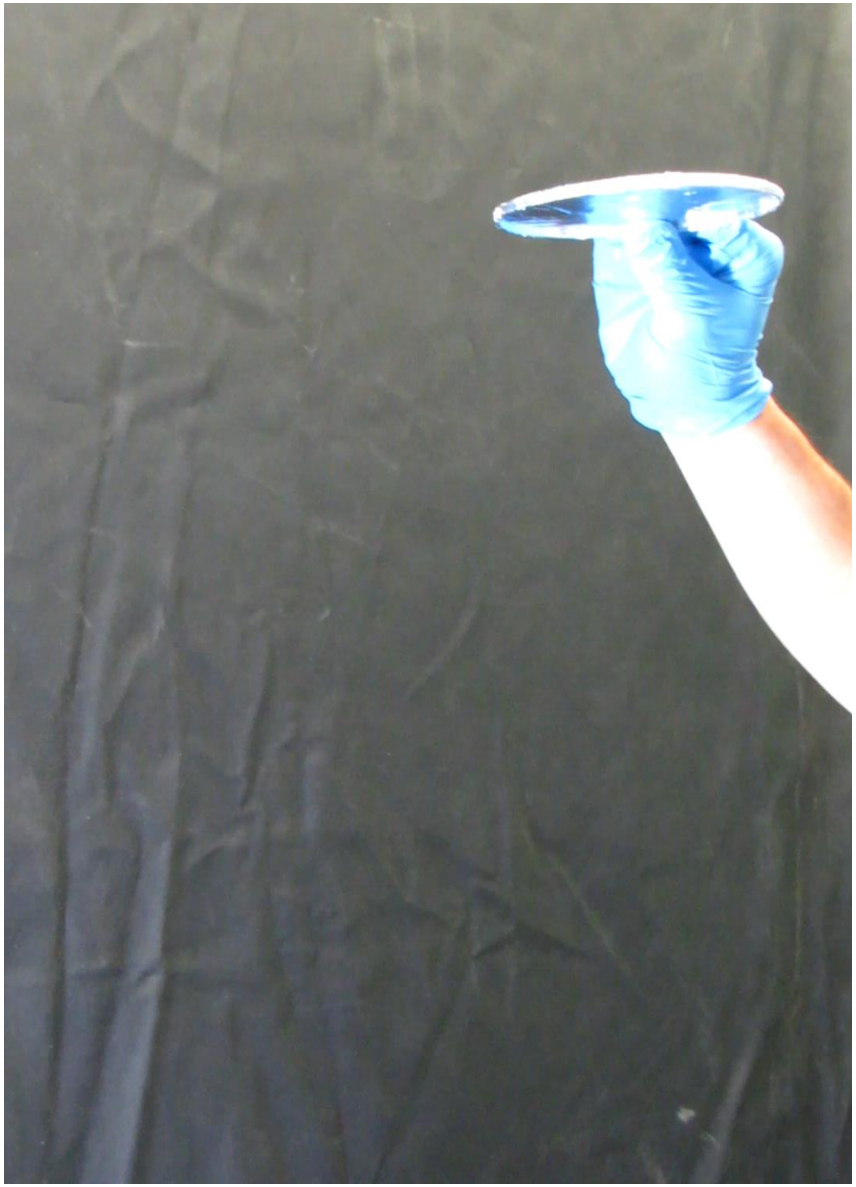
Raindrops: 1-5×

~1 cm bird

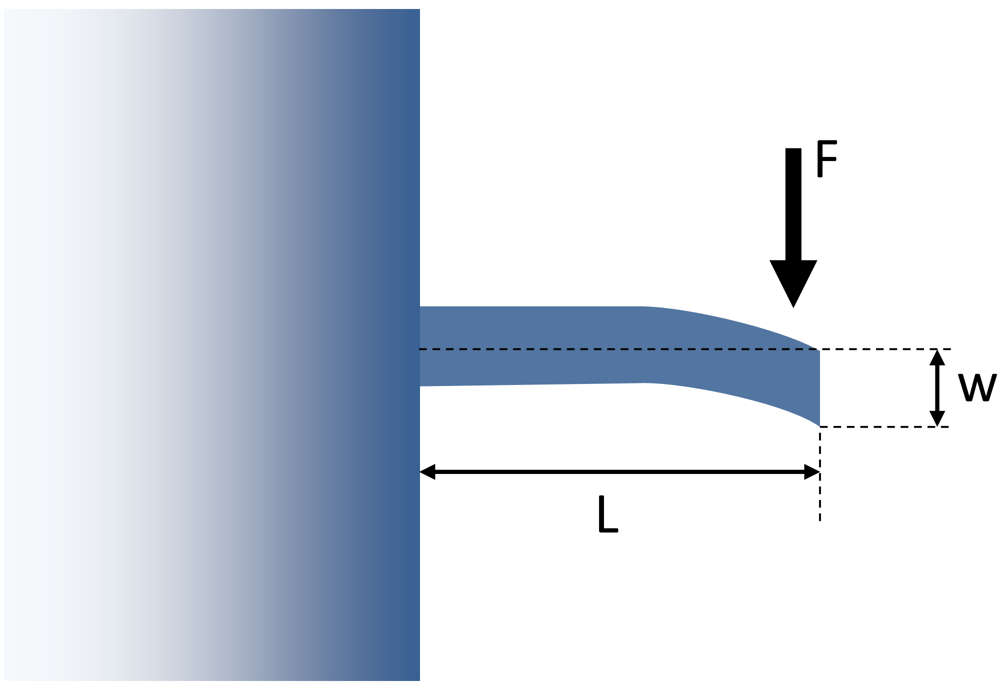
bone:1000×

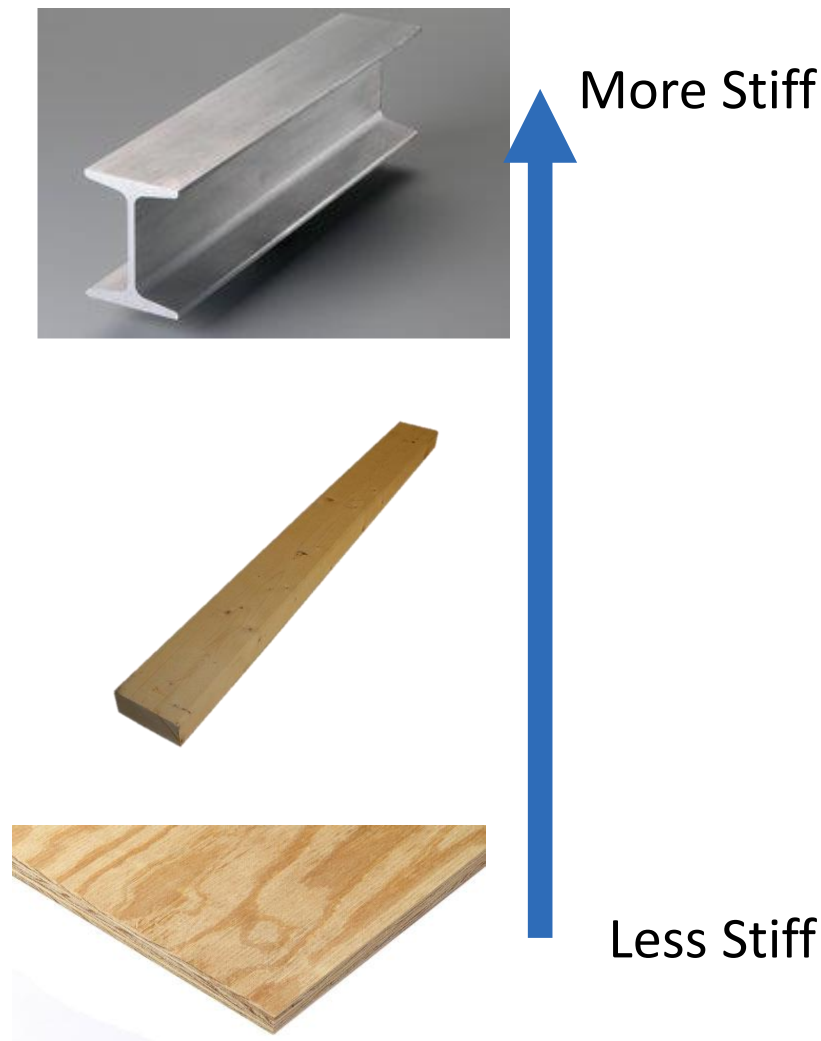
Plate "Floating" and "Gliding"





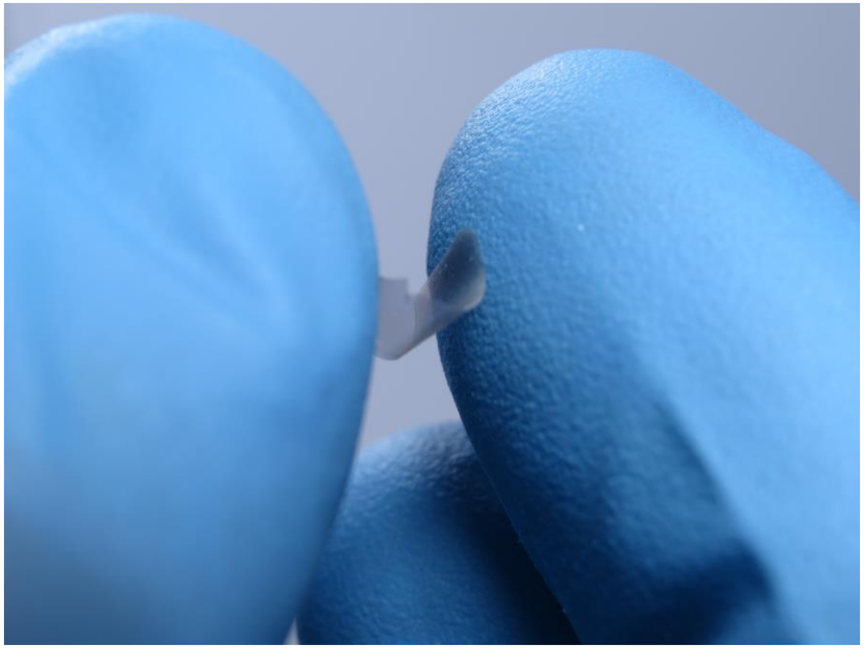
High Bending Stiffness and Rigidity under Self-weight

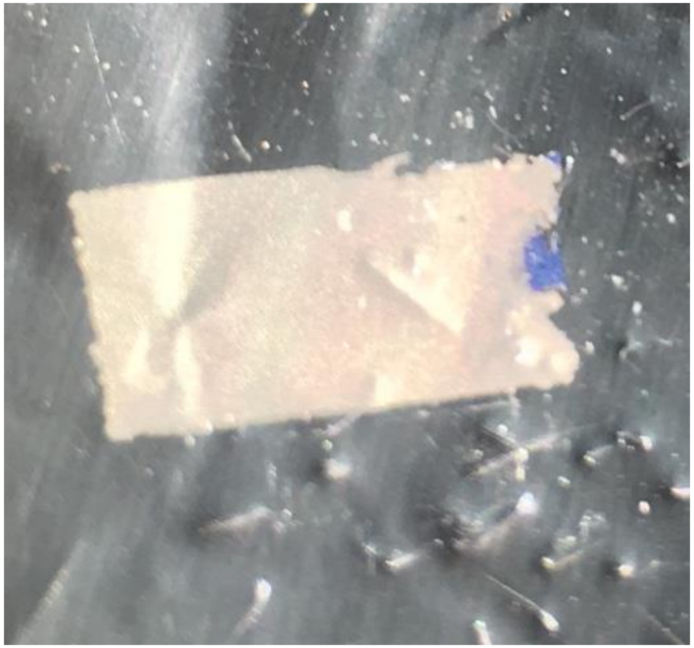




High Bending Stiffness and Rigidity under Self-Weight

Bending Stiffness about 30x greater than planar film of same thickness





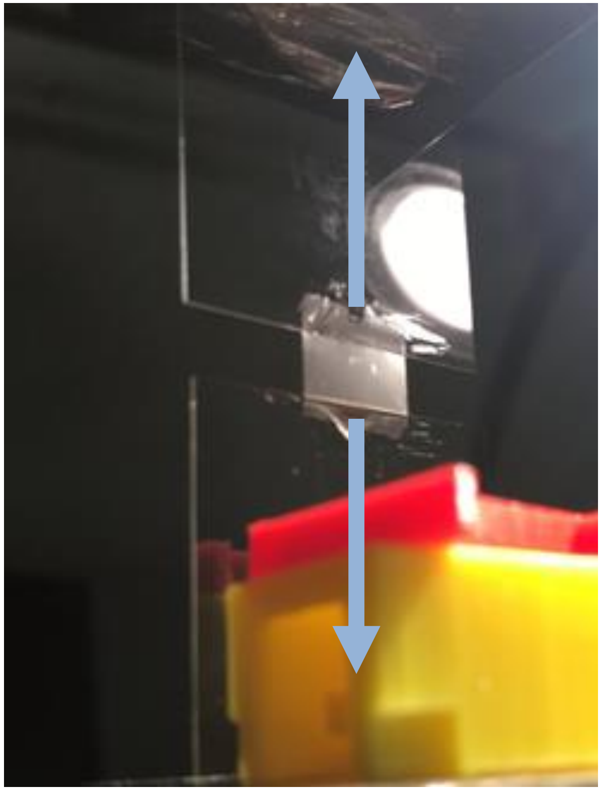
Can easily bend (like aluminum foil or paper) with applied force

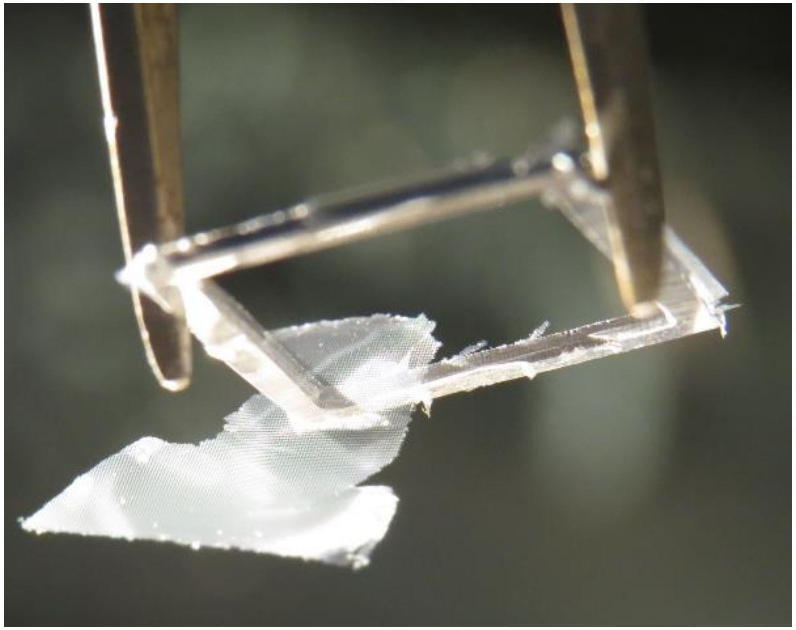
…through will hold it's own shape without applied force

…and return to it's original shape after deformation

Shape recovery after large deformations (recorded SEM feed)

Limitations in Stiffness and Shape





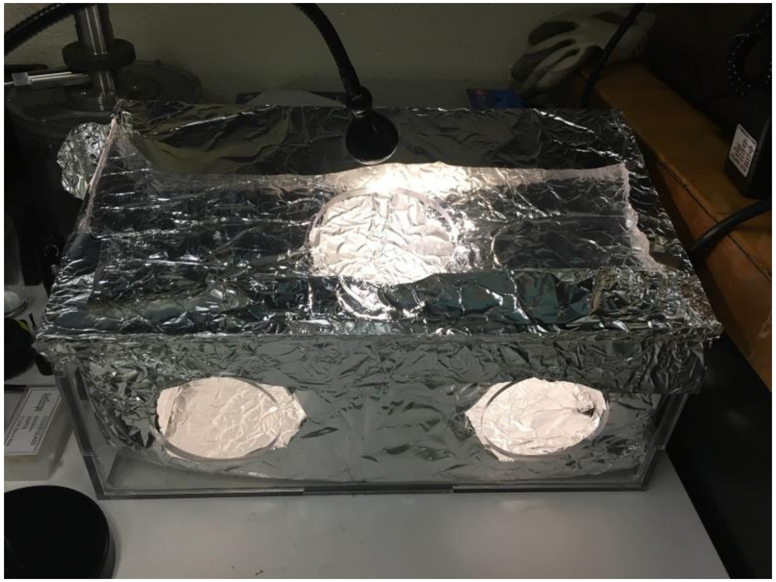
Fragile! – can be easily torn – withstands 1% tensile strain

Expandable! – Young's Modulus ~130 GPa – 1-cm wide strip accommodates 20-40 mN - ~10× larger than comparable plastics

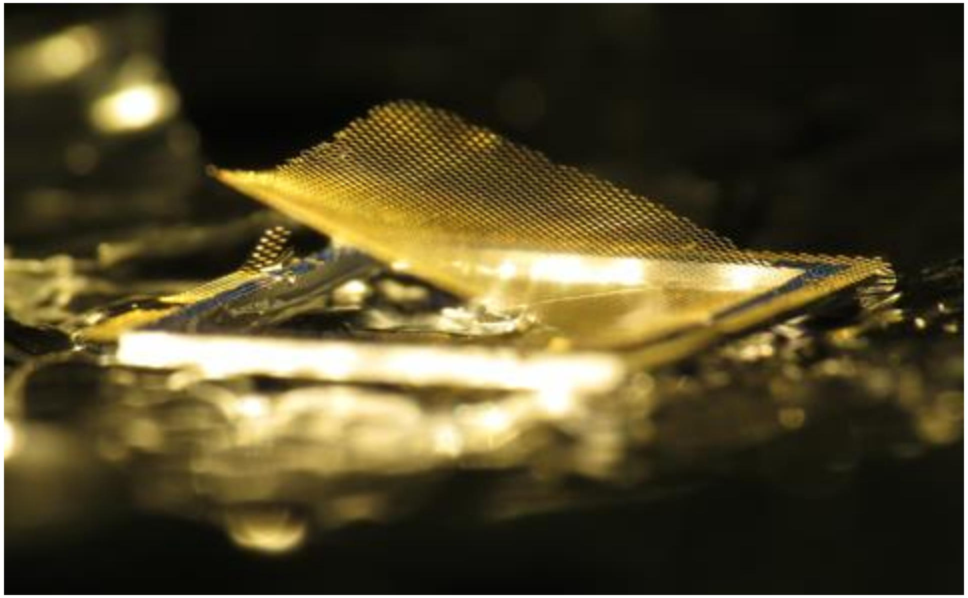
Practical Challenges and Opportunities

- Sticks to very smooth surfaces (like glass or countertop)
- Doesn't stick to rough surfaces (like aluminum foil)

- Natural bending can be controlled



Aluminum foil-covered handling box to make sure plates don't fly away



Intrinsic Strain = Natural Curl
cm-scale radius of curvature

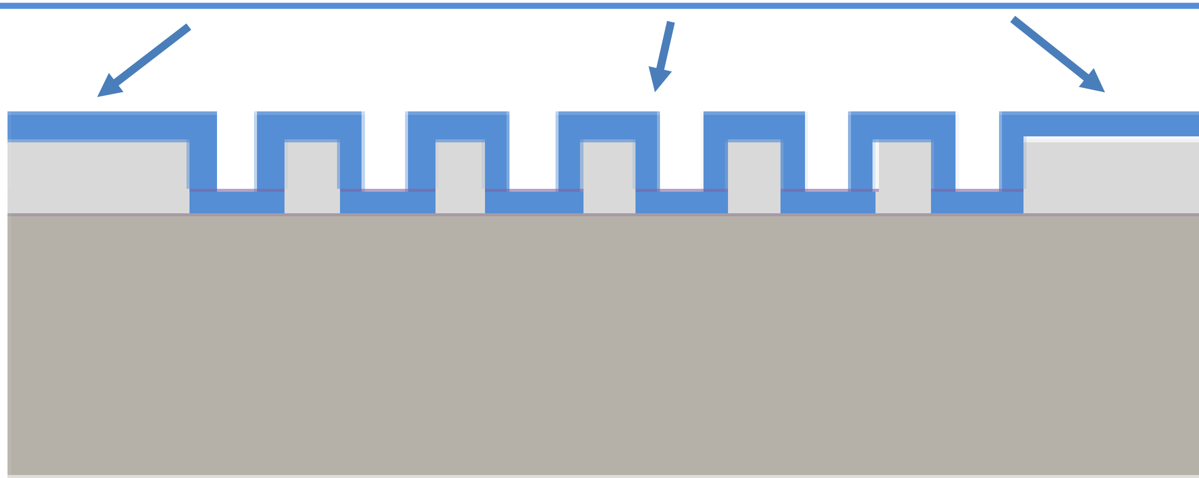
Options for Materials

Alumina and Hafnia (Hafnium Oxide)

Copper and other metals via electrodeposition

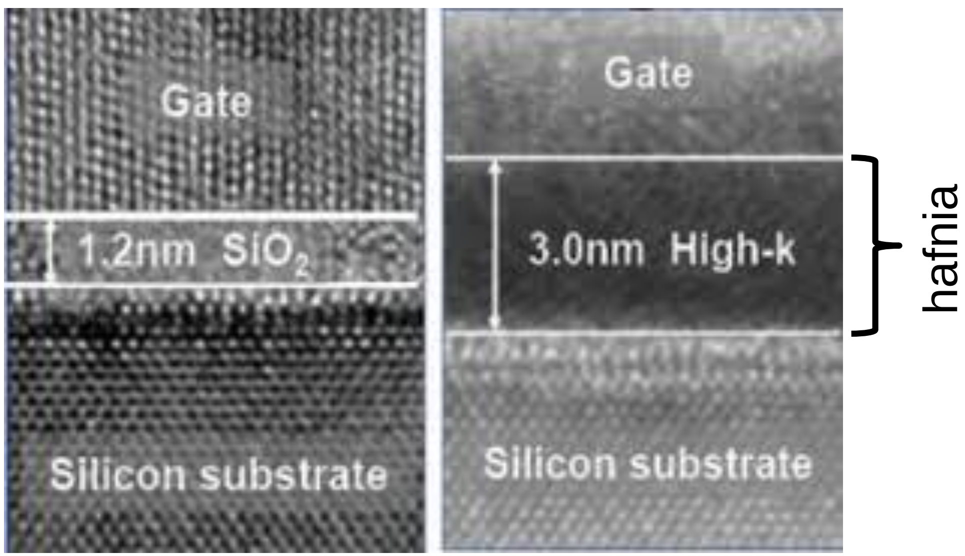
Chemical vapor deposition or atomic layer deposition

"Any" Conformal Layer can produce the nanoplate

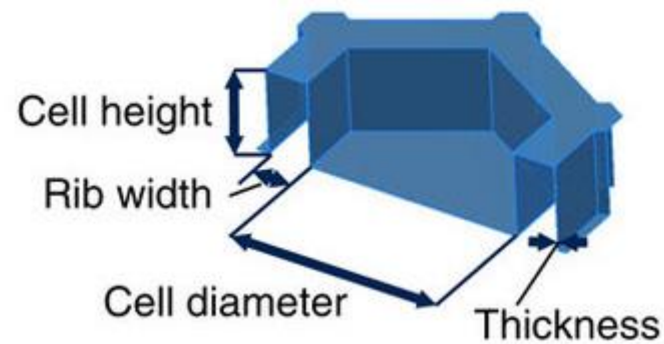


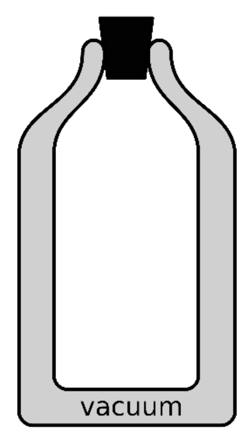
Electrically and Thermally Insulating

Nanometer-thickness used in transistors (switches on computer chips

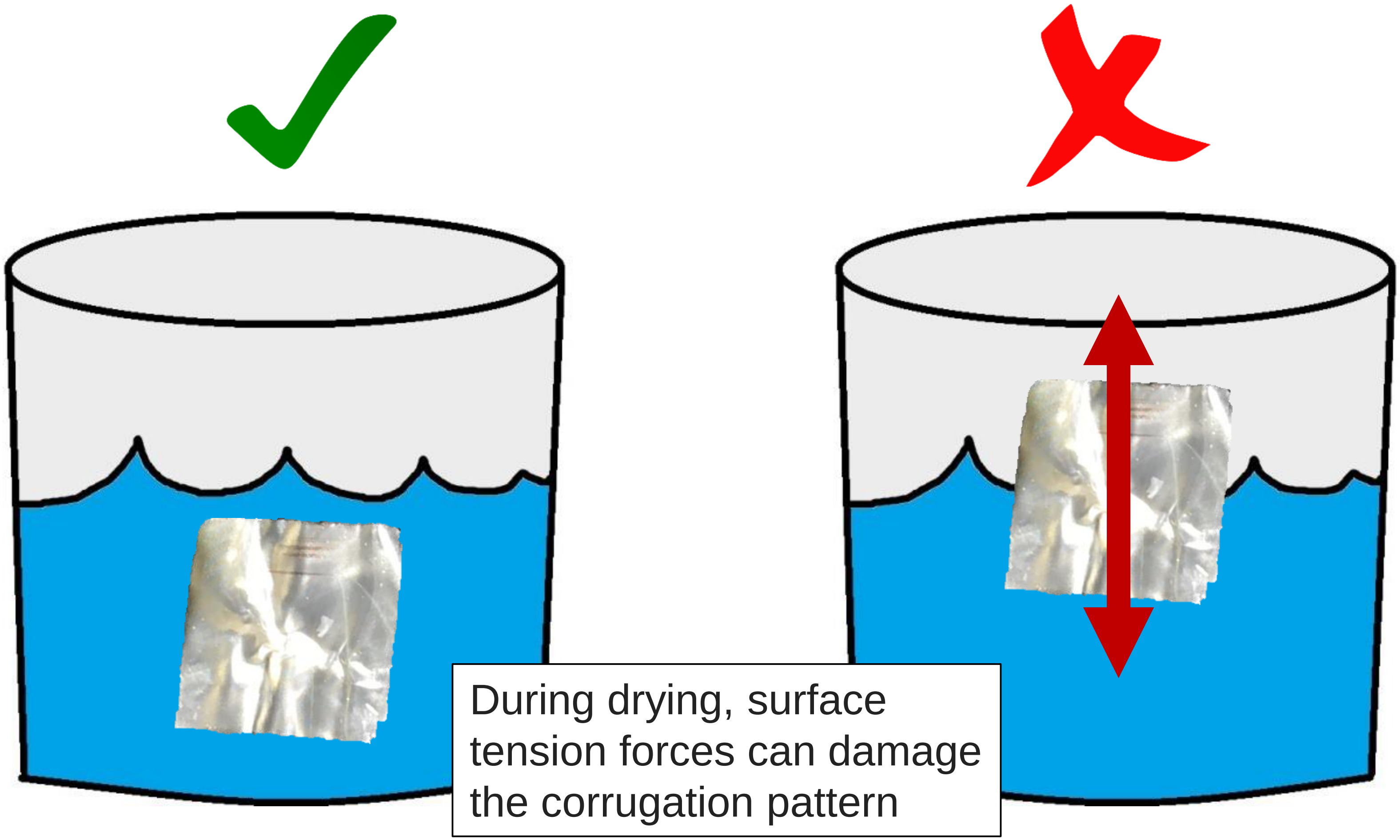


Cell Height (1-10 μm) provides gap between top and bottom





Further Limitations: not friendly with liquids

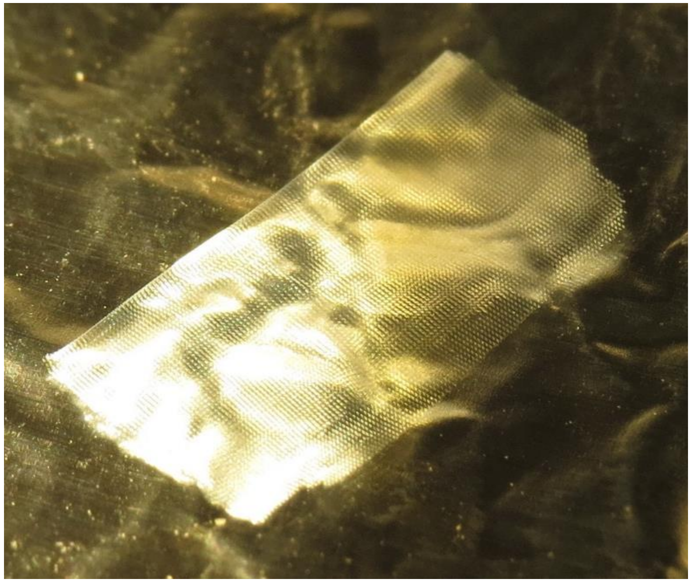


Permanently Submerged

Submerged and Removed

Further Limitations: Currently Research-scale Production

Research-scale: 1-2 cm^2



Business-scale: wafers

300 mm diameter

700 cm^2

Research-scale: $1000(?)

Business-scale:

$500 / wafer

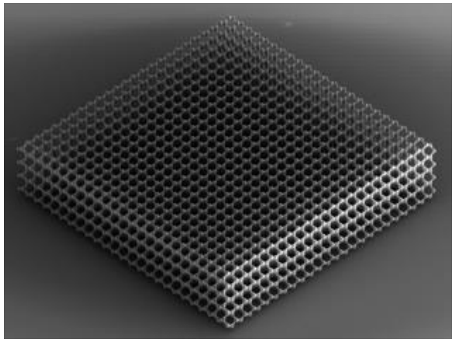
<$1 per cm^2 at high-volume manufacturing

Some ideas for possible applications

Films for High-frequency microphones and acoustic metamaterials

Wikipedia

High-fidelity ribbon microphones, fabricated with our light metamaterial, could be operated above 100kHz



Daraio Group @ ETH Zurich

Our plates can produce microstructures for acoustic insulation or filtering

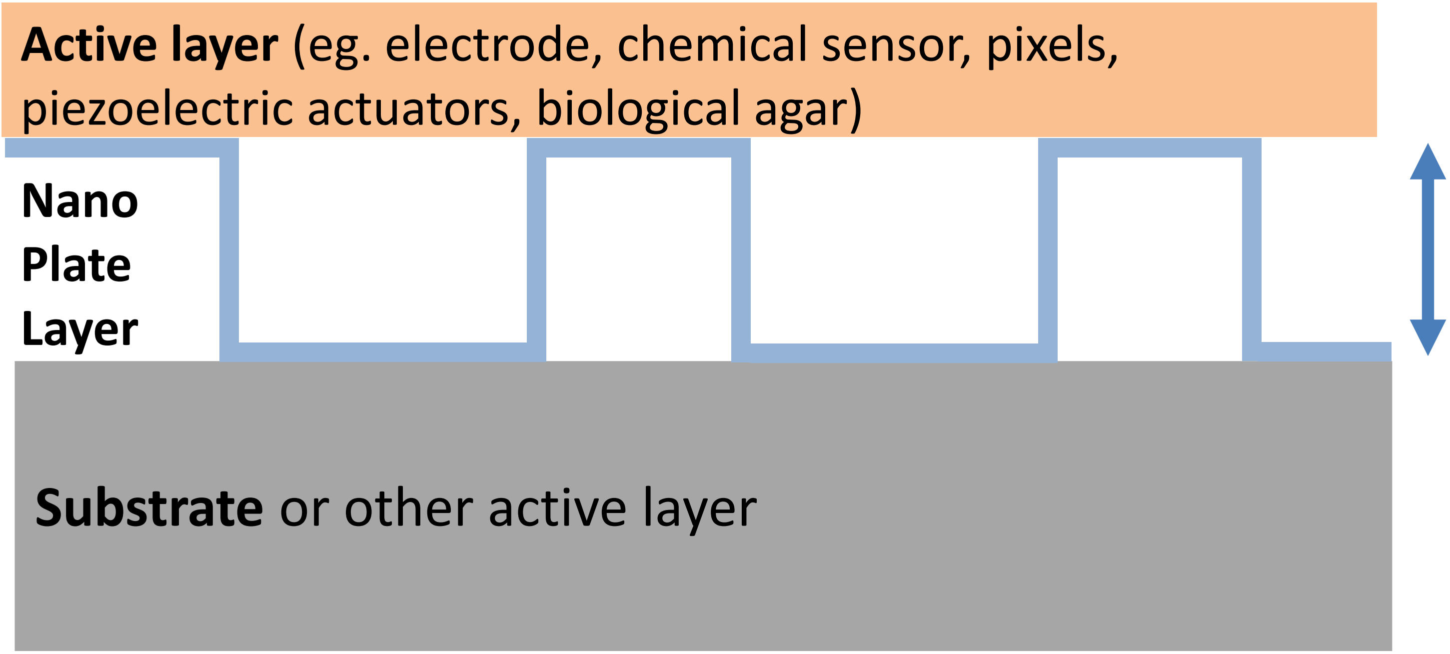
Materials for microflyers/robots (continuous membranes)


Sources: Wikipedia, http://micro.seas.harvard.edu/

We can make wings more than an order of magnitude thinner and lighter than any wings created by nature (~ 10 μm) or man (>0.5 μm) so far

Some ideas for possible applications

Thermal and/or Mechanical Isolation in Devices

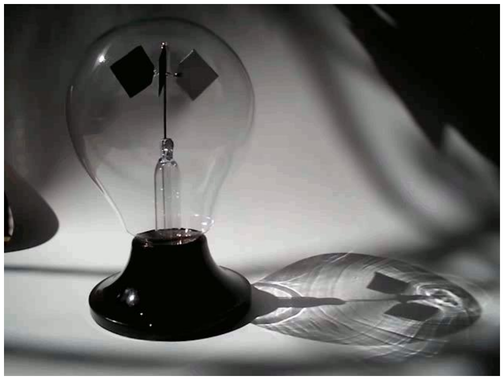


Thermal: Air or vacuum gap for temperature independence

-or-

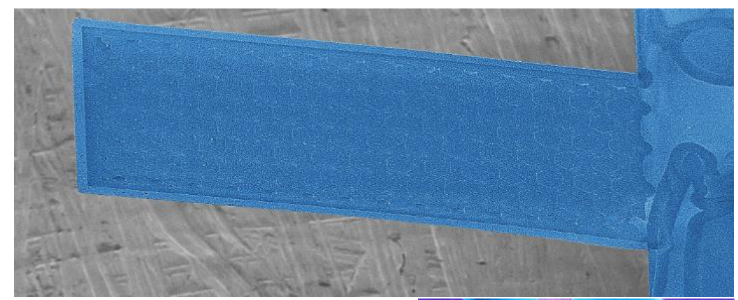
Mechanical: Gap for shock resistance, spreading force over in-plane layer

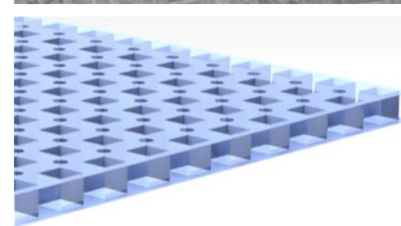
Long-term dream/vision: Levitation and propulsion using Knudsen Force

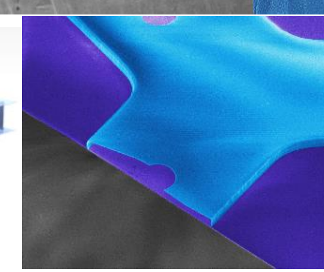


https://en.wikipedia.org/wiki/Crookes_radiometer

- Knudsen force exist on plates that have different temperatures on the two opposite sides. It powers a popular toy/device called Crookes radiometer (left)
- The Knudsen force is enough to make the vanes rotate on a low-friction bearing but is are about 100 times too small to overcome gravity and make the paper levitate

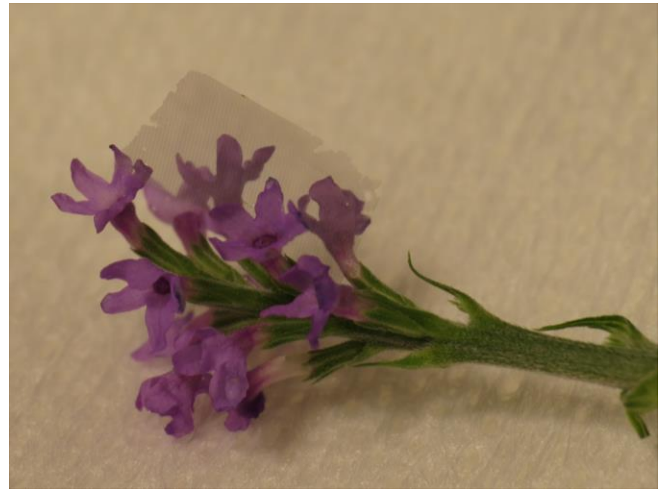






Our plates are thousands times lighter than paper but can maintain a large temperature difference between the two sides when illuminated by, say, a laser pointer

Reliable Knudsen propulsion/levitation will take a few more years of R&D



Thanks & Questions

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