Evaporation of sessile drops on flexible membranes with capillary origami

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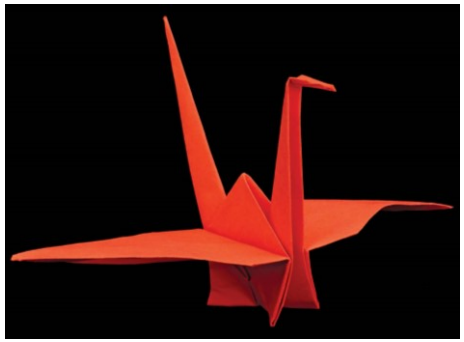
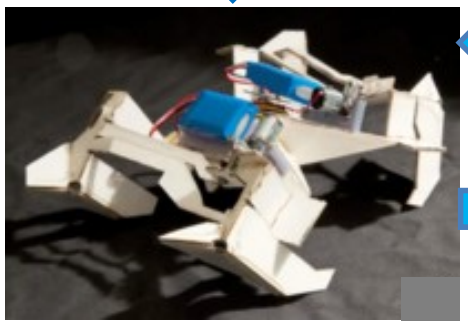
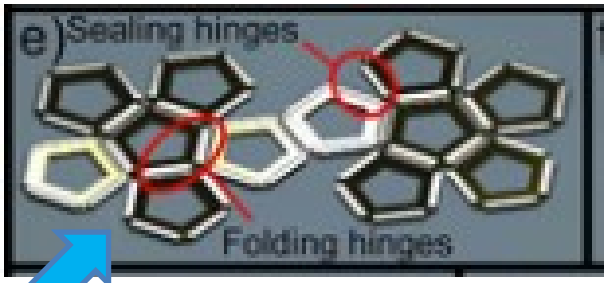
Artistic origami

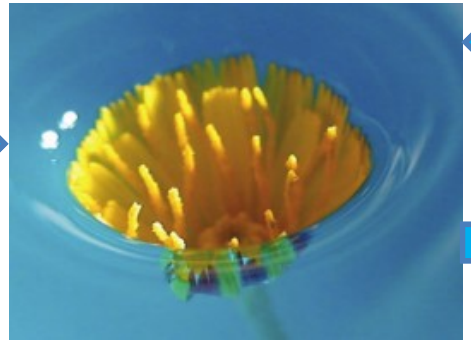




Scientific/ industrial origami

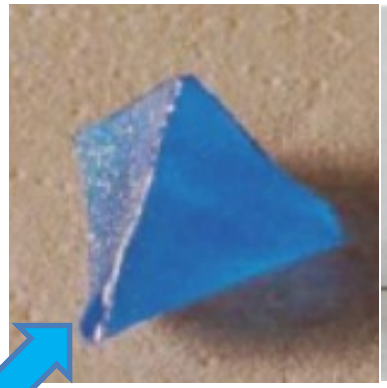
Hinge joint

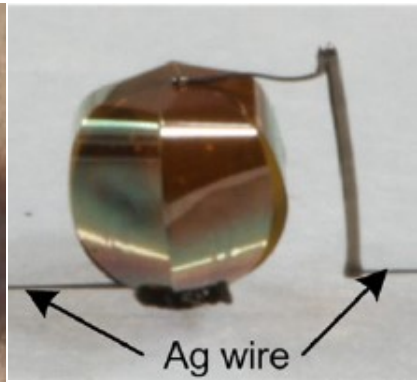


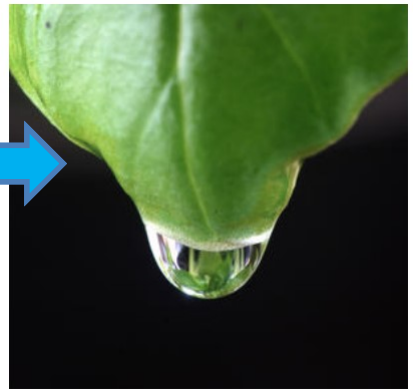


Capillary origami

Fabrication at micro/nano scale

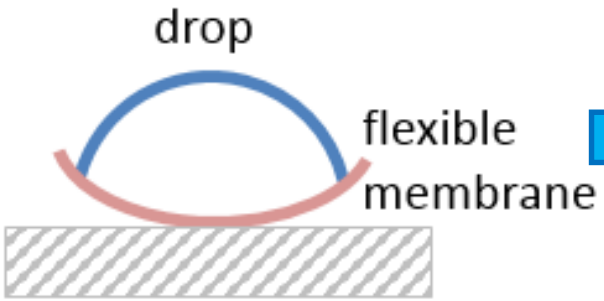




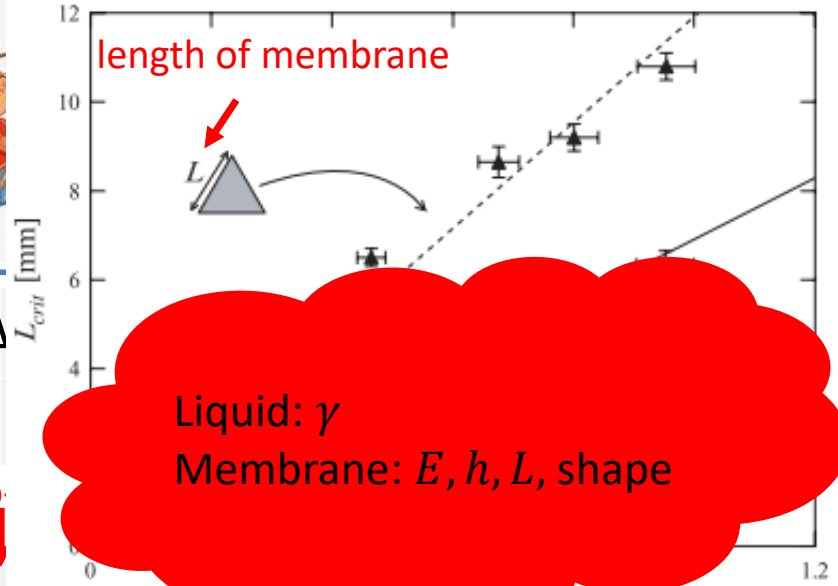


Evaporation with origami

What is capillary origami?



Py, C. et al.,The European Physical Journal Special Topics, 2009



Liquid: γ
Membrane: E, h, L, shape

Δ

elasto

length

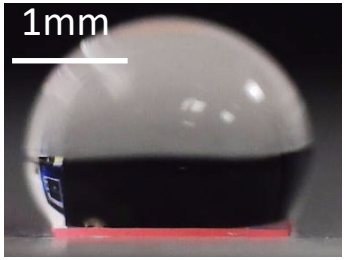
s

L_E

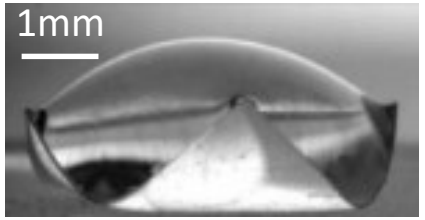
0.5

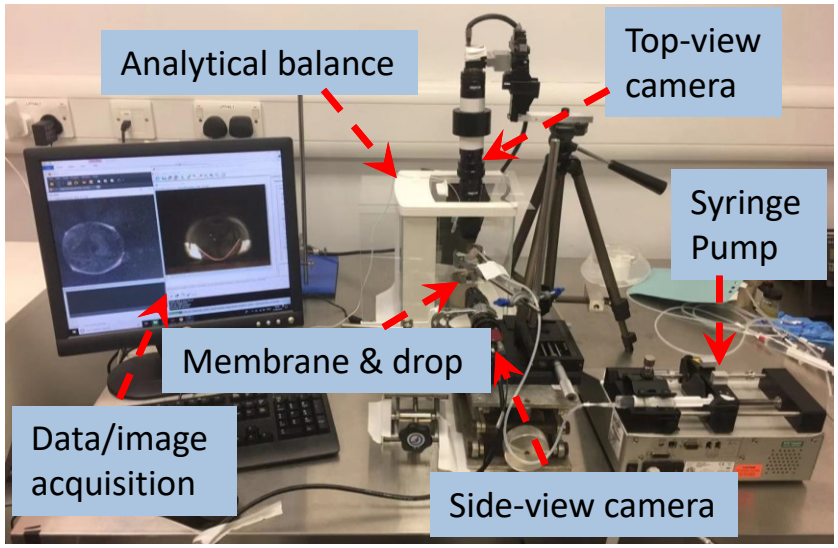
$\boldsymbol{Square}$: L_{crit}=7.0L_{EC}
$\boldsymbol{Triangle}$: L_{crit}=11.9L_{EC}

Unfold



Fold





Experimental set-up

Experimental conditions:

Drop liquid	Membrane size, mm	Drop mass, mg	Temperature, °C	Vapor concentration,%
Water	2×2	4.5±0.2	22 ± 1.2	$H = 44 \pm 4$
Ethanol	4×4	4.0±0.3	22 ± 1.2	0

Spinning speed, w /rpm	500	1000	1250	1500	1750	2000
Thickness of PDMS, h/ µm	180	71	48	40	36	30
$B = Eh^3/12\,(1-\vartheta^2)$	Decreasing bending stiffness →					

Fabrication of PDMS membranes

Clean mica substrate

↓

Mix the monomer and crosslinker at mass ratio, 10:1, and a tiny bit of silicon pigment

↓

Degas in a vacuum degasser for half an hour

↓

Spinning coating at various spinning speeds for 60s

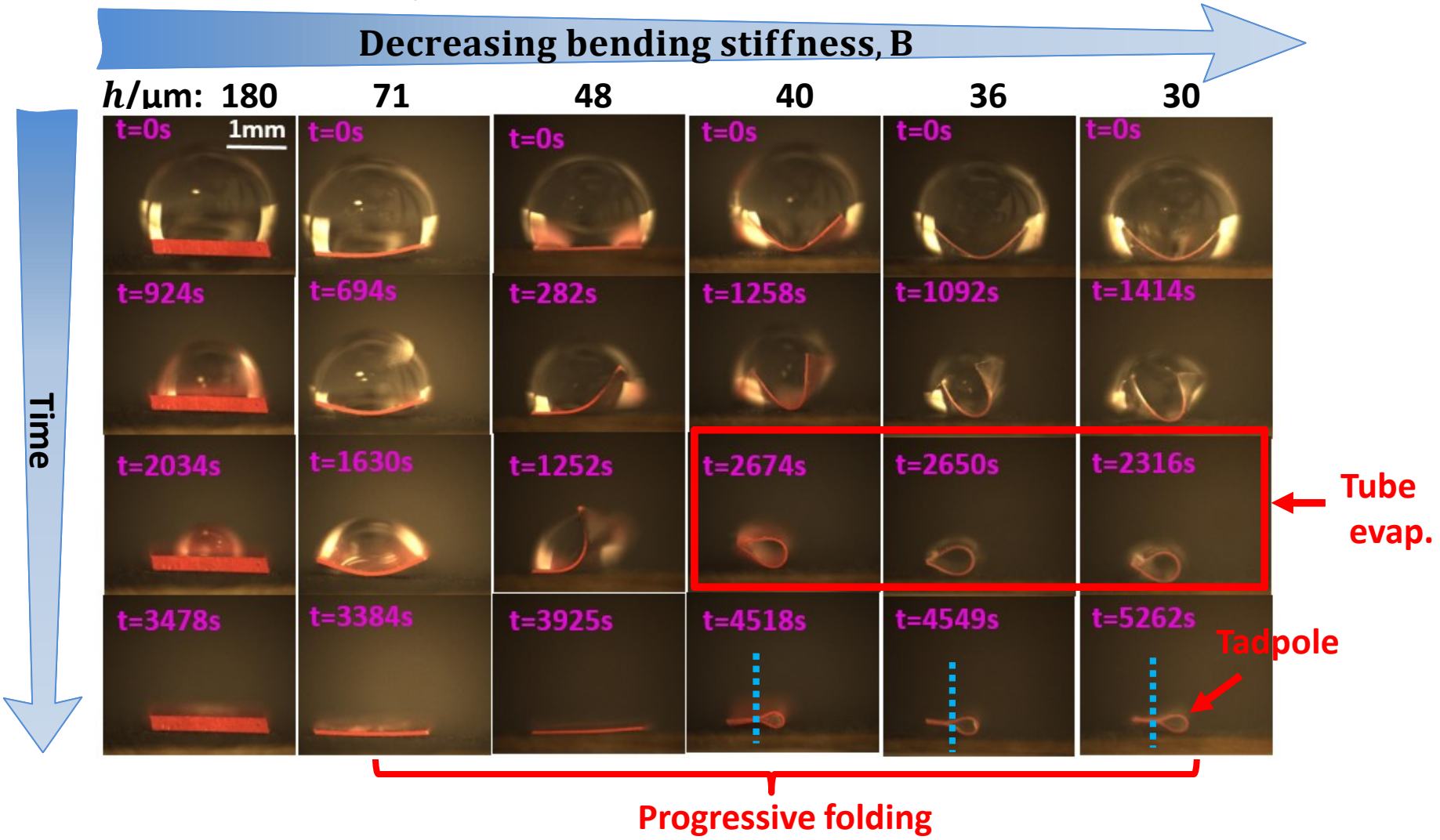
↓

Dry substrates in oven at 80°C for 2 hours

↓

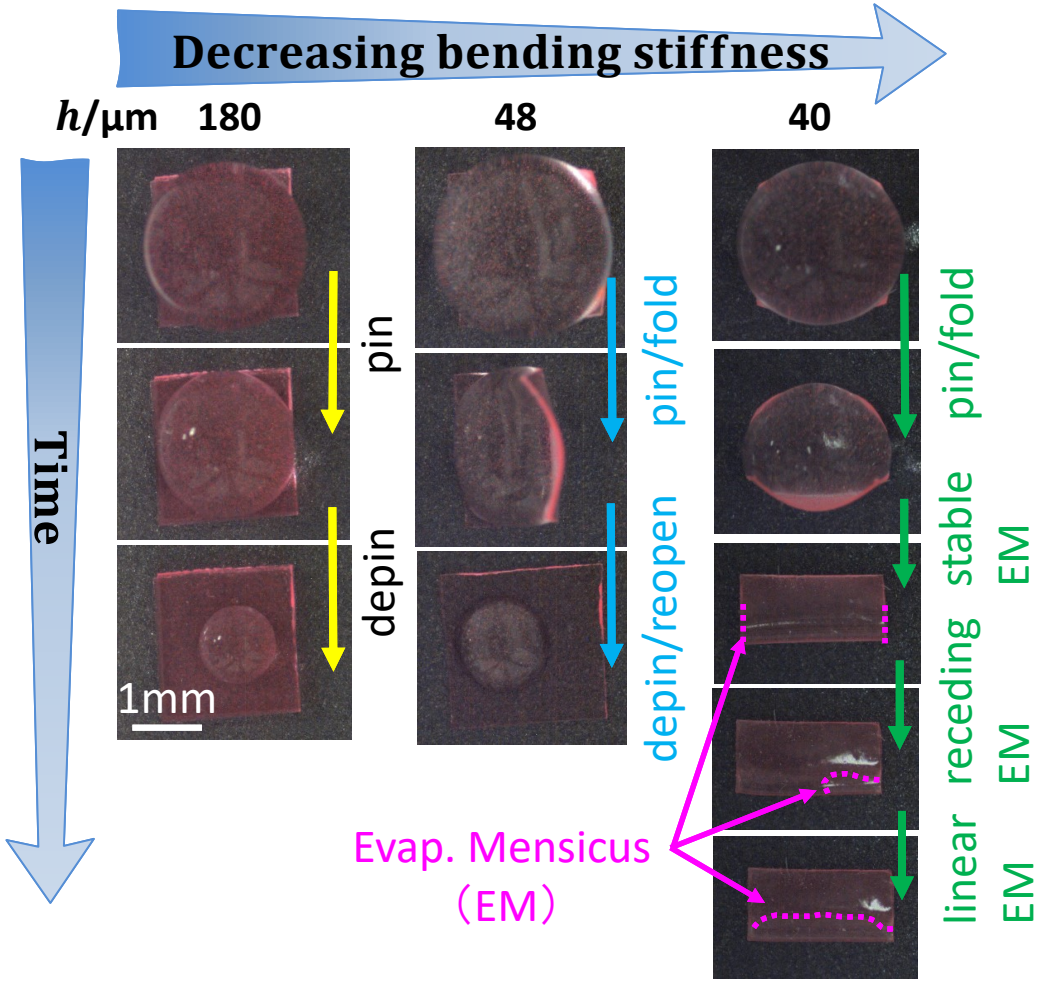
Substrates of different thicknesses

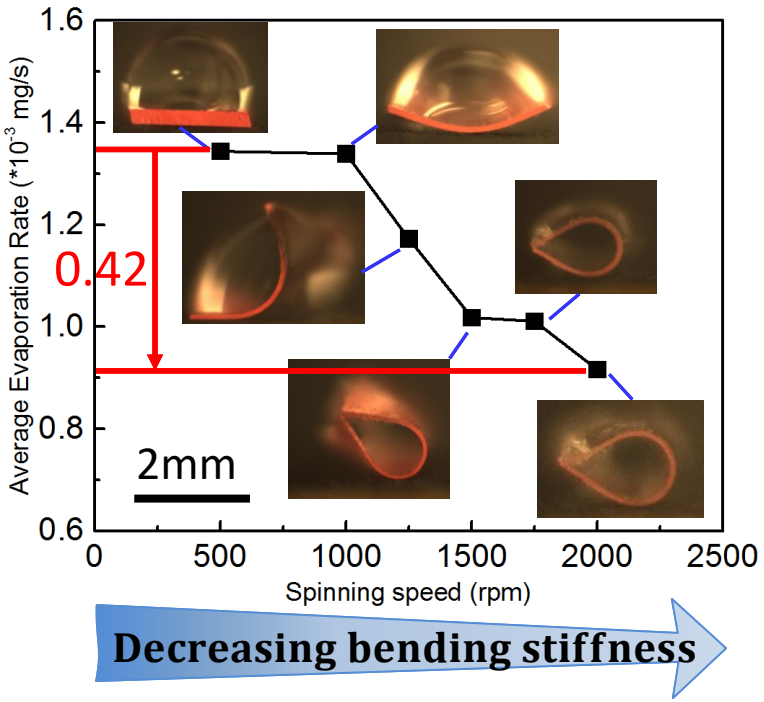
- Water drops



Folding process of flexible membranes (side view)

- Water drops

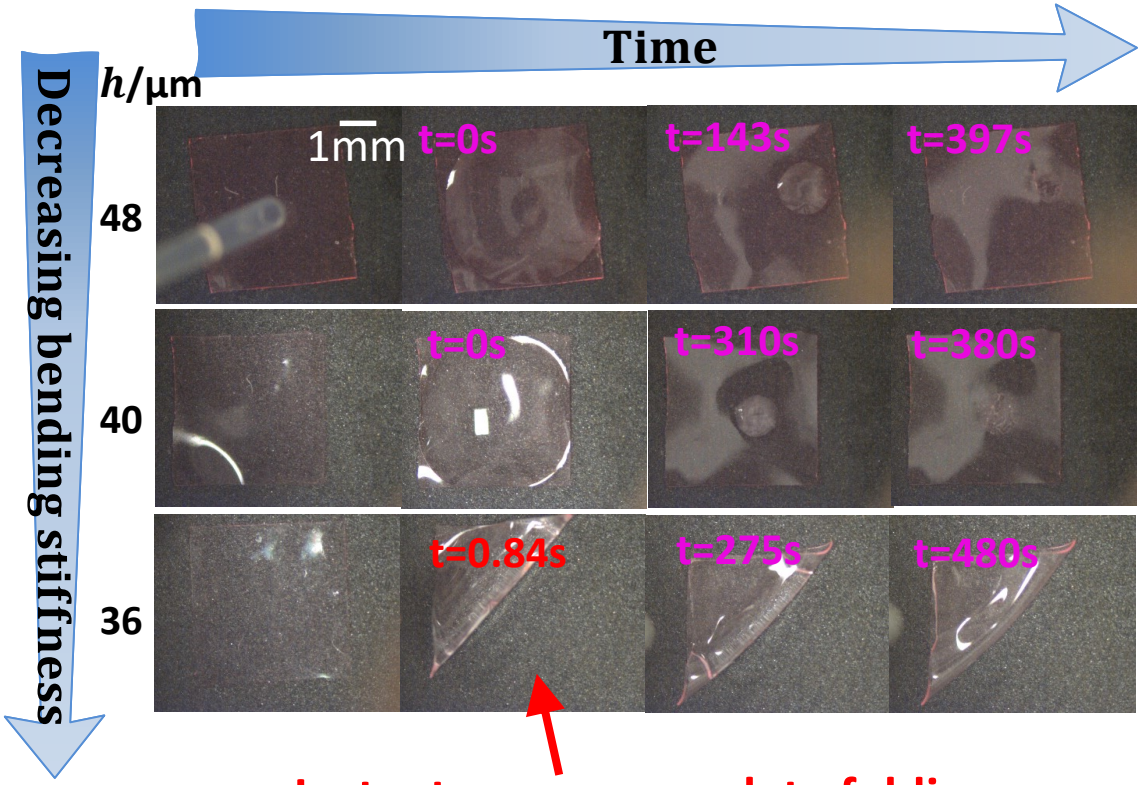




Average evaporation rate:

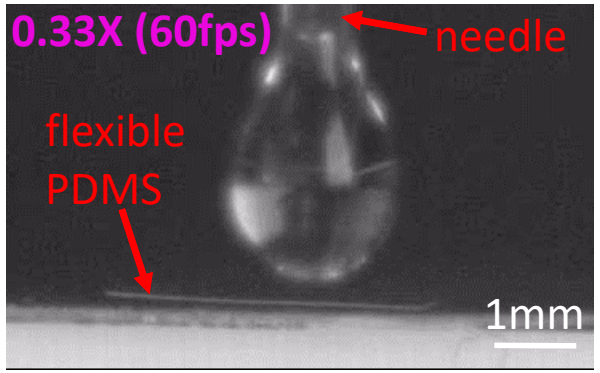
$$\dot{m}_{av} = m_0 / t_{life}$$

- Ethanol drops

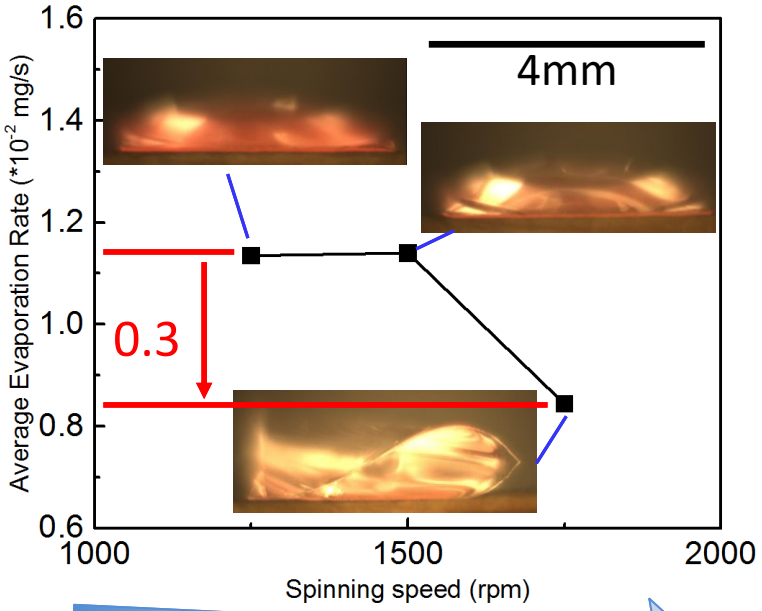


Instantaneous complete folding

Folding process of flexible membranes (top view)



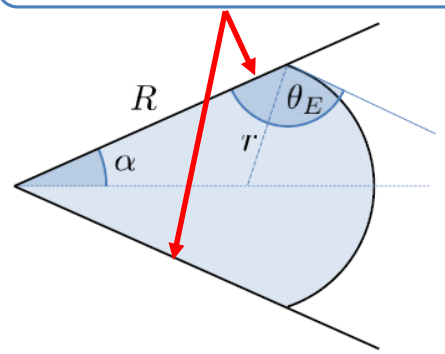
Instantaneous complete folding

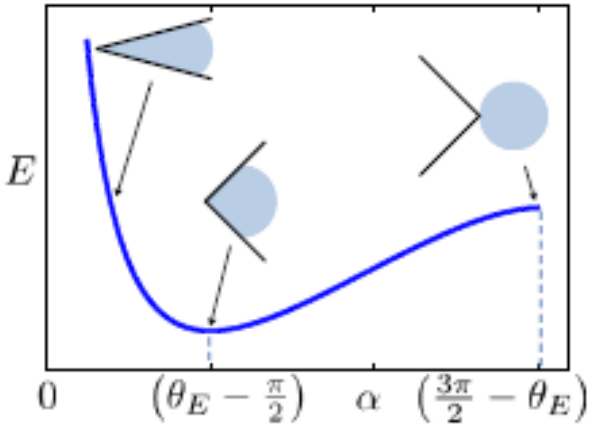


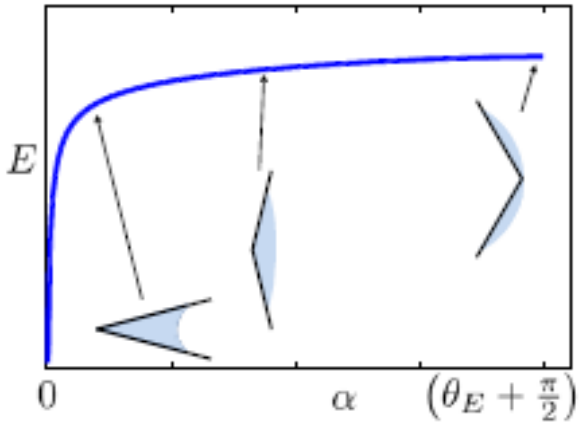
Decreasing bending stiffness

➢ Progressive folding ***VS.*** instantaneous folding

Freely articulated infinite walls







2D model:
total surface energy E
varies with folding angle α

Omniphobic case:
E_{min} at stable folding angle
$\alpha = \theta_E - \frac{\pi}{2}$

Ominiphilic case:
E_{min} at $\alpha = 0$

Peraud, J. P.; Lauga, E., Physical review. E, 2014

Present cases:
Water drop: $\theta_E = \mathbf{110 \pm 2°}$
Ethanol drop: $\theta_E = \mathbf{32 \pm 2°}$

Conclusions:

- ✓ The evaporation state of a drop depends on the folding of flexible membrane. The classical drop evaporation can transit to the evaporation of meniscus of different shapes.
- ✓ The average evaporation rate of drop decreases with the folding extent of flexible membrane.
- ✓ The wettability of liquids mainly determines the folding speed of flexible membrane when capillary origami can occur.

Future work:

- ❖ To analyze the dependence of instanenous evaporation rate of drop in different evaporation states on the folding extent of membranes.

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Questions:

- What is deposition pattern after drops containing particles dry on the folding membrane?
- How to make use of such particle deposition in 3D fabrication?