Toward adiabatic computation

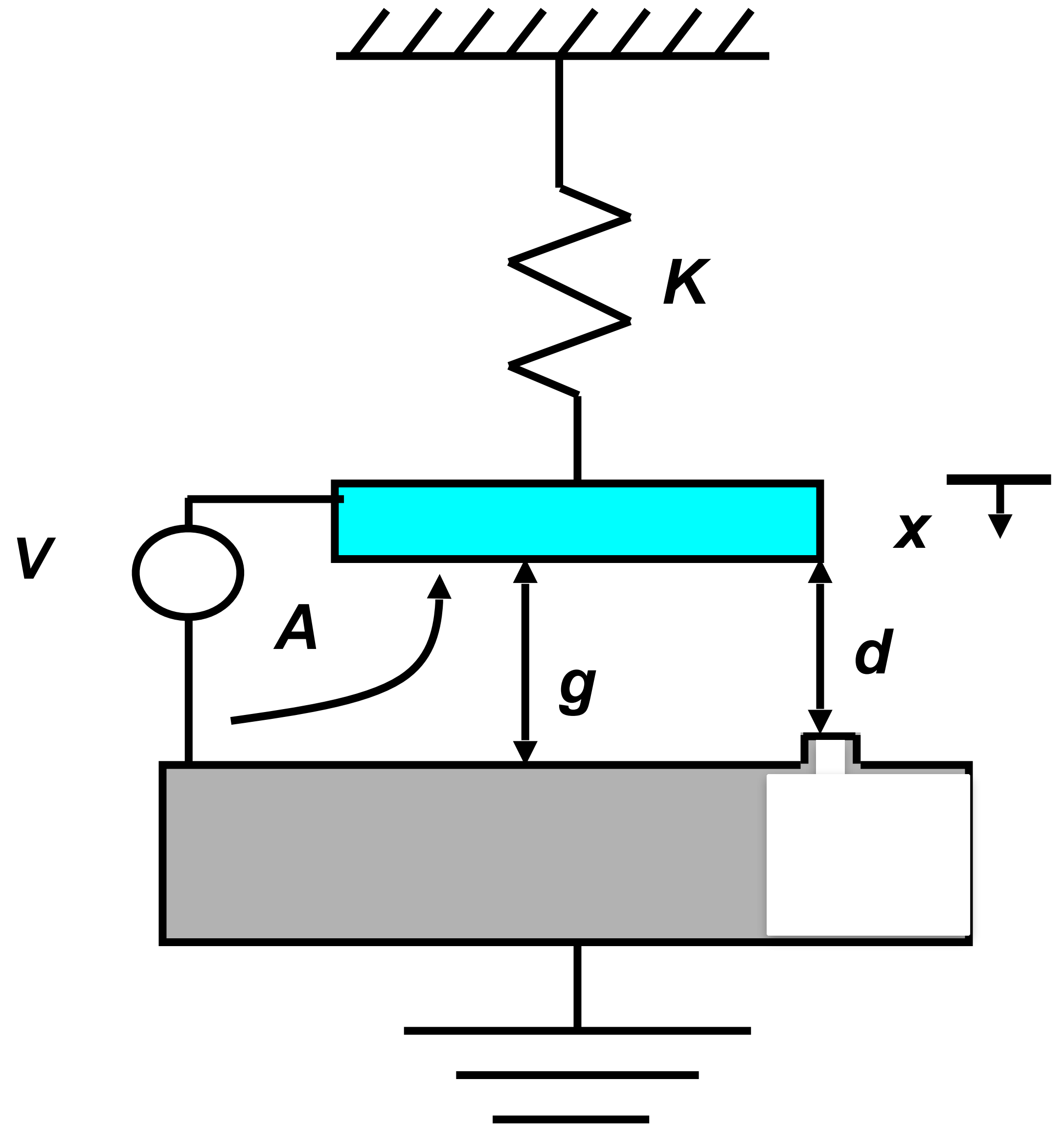
July 10, 2015

NiPS Summer School 2015
ICT-Energy: Energy consumption in future ICT devices

Outline

- Performance of NEMS switches: reality vs. necessity
- Adiabatic NEMS-based logic circuits
- Adiabatic MEMS logic gate
- Adiabatic NEMS memory device

Electrostatic NEMS Switches (back to basics)



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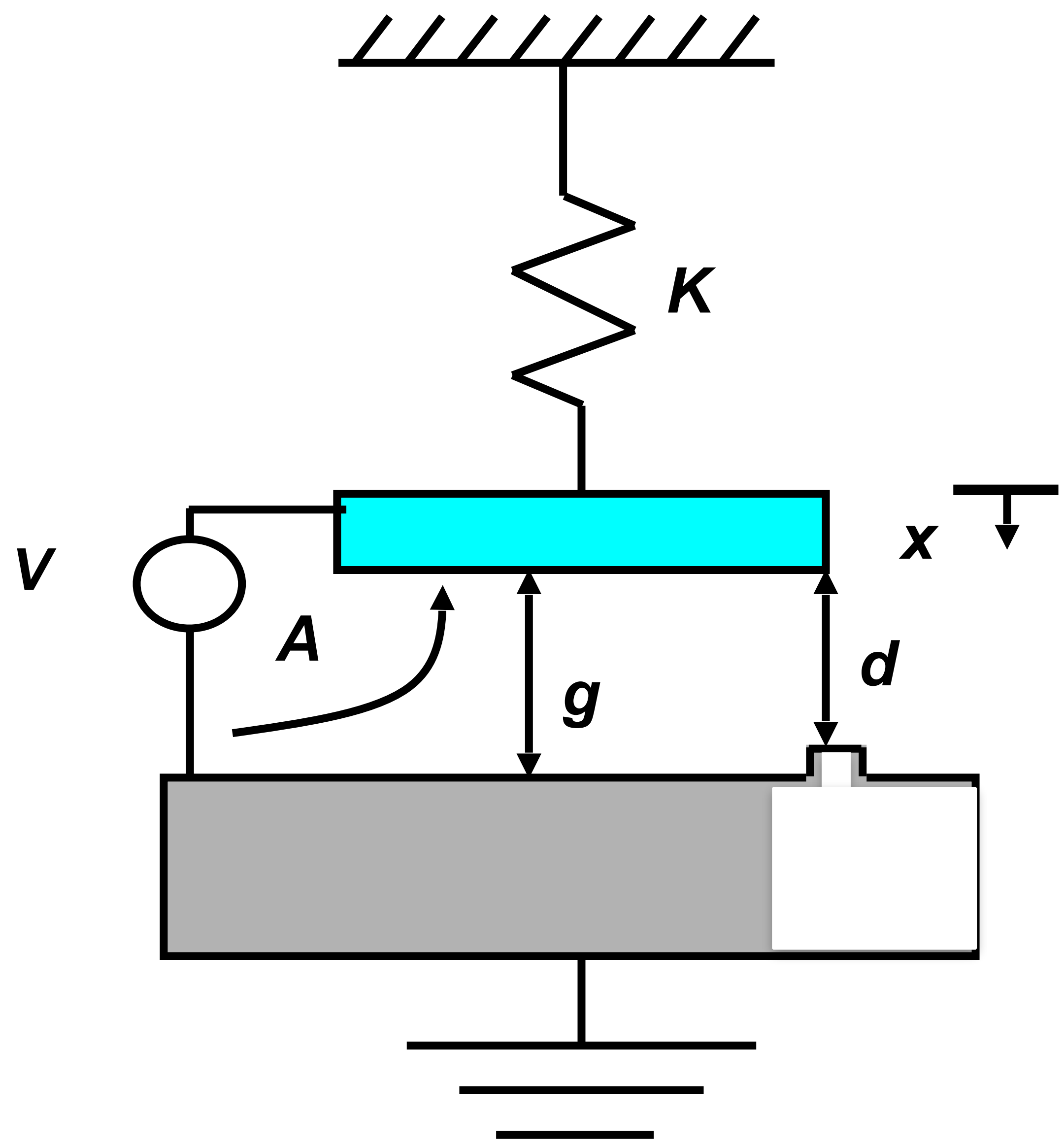

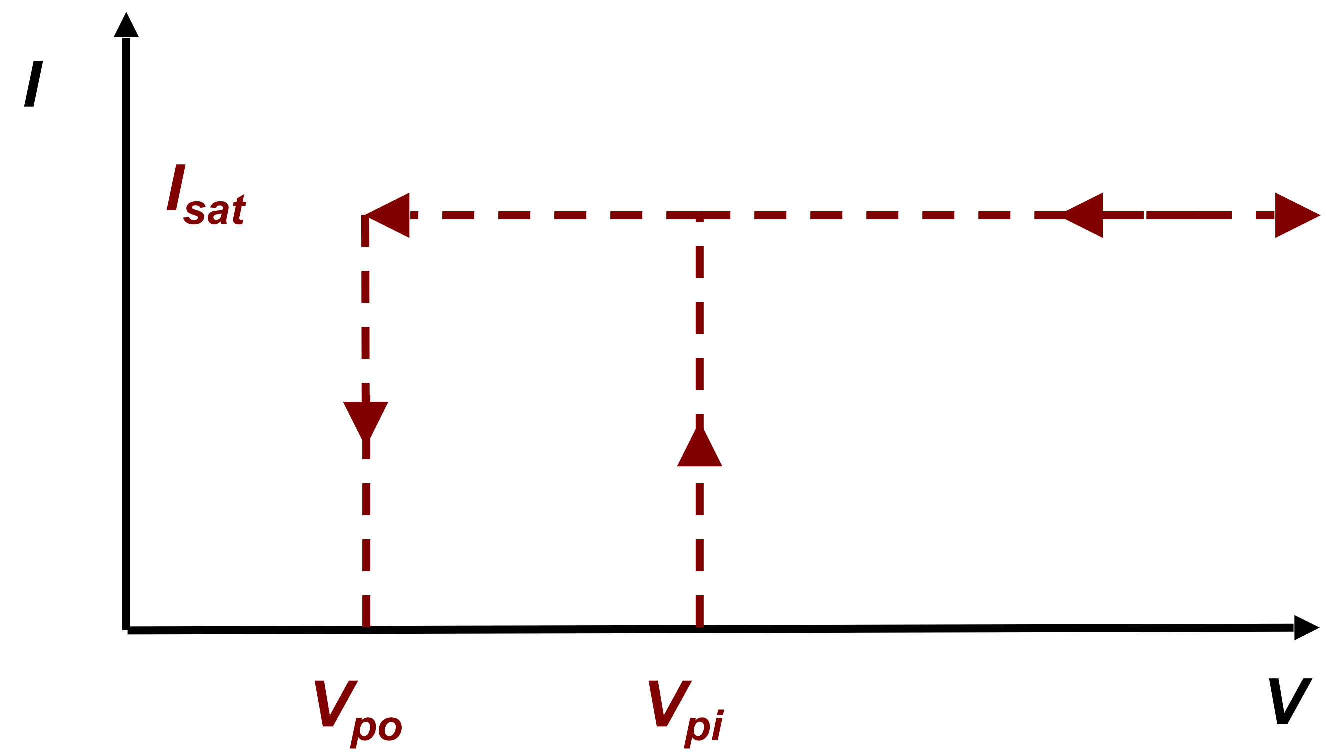

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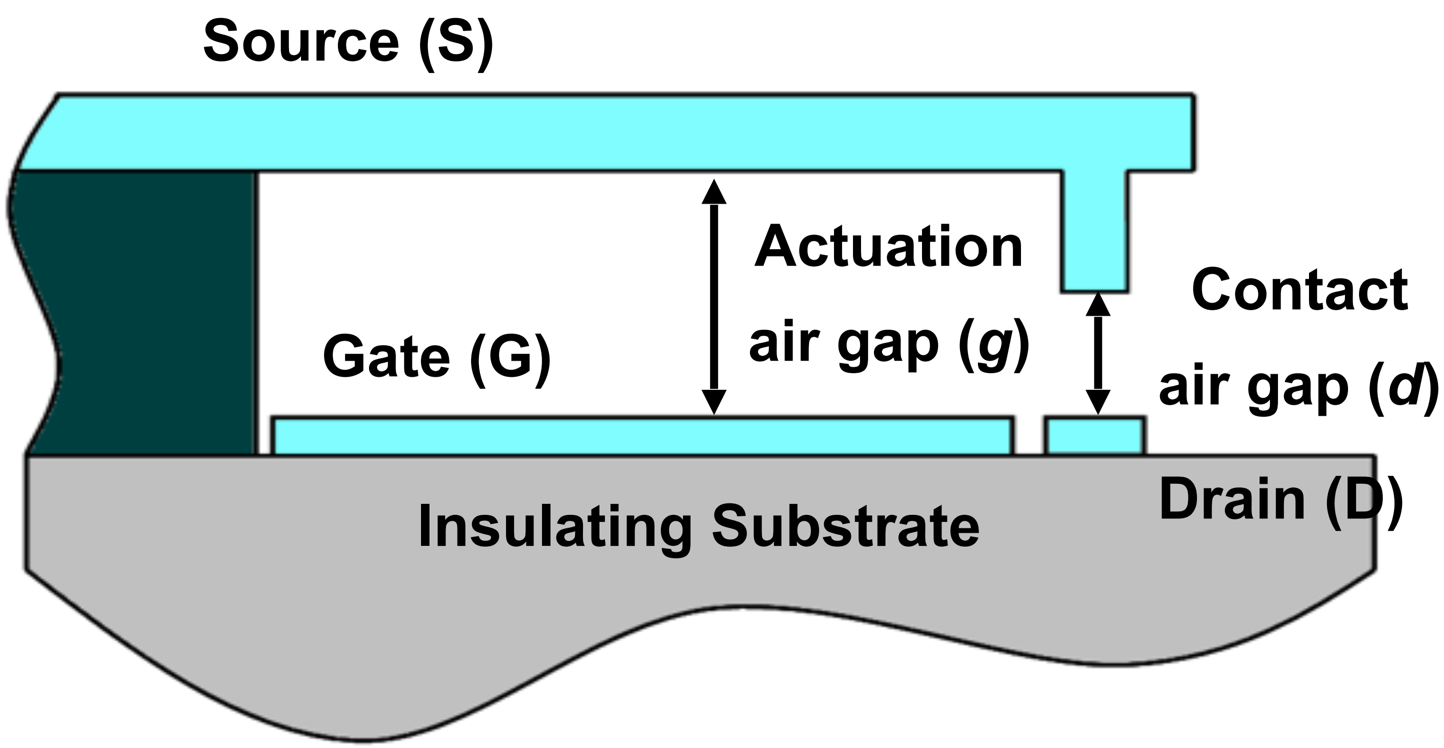

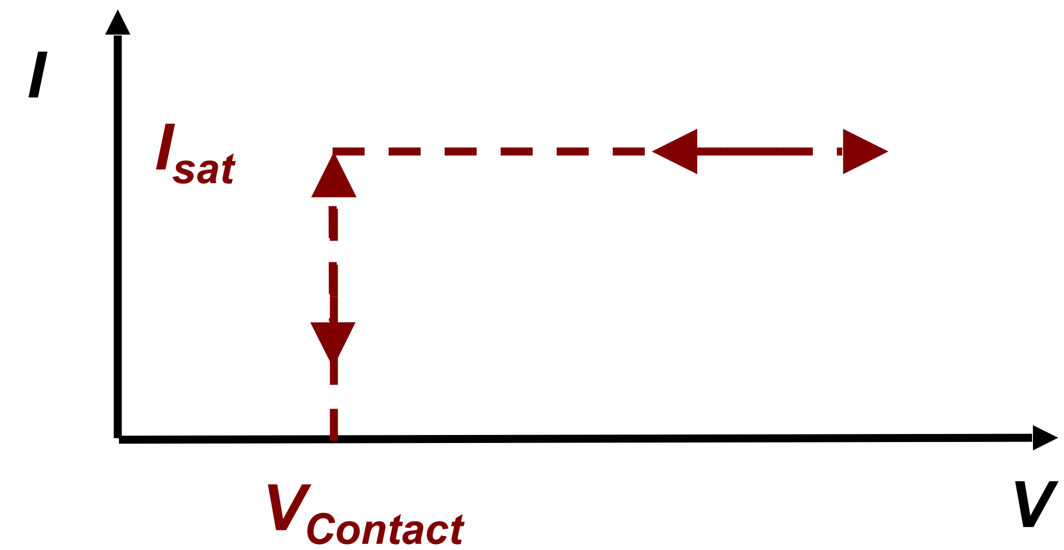

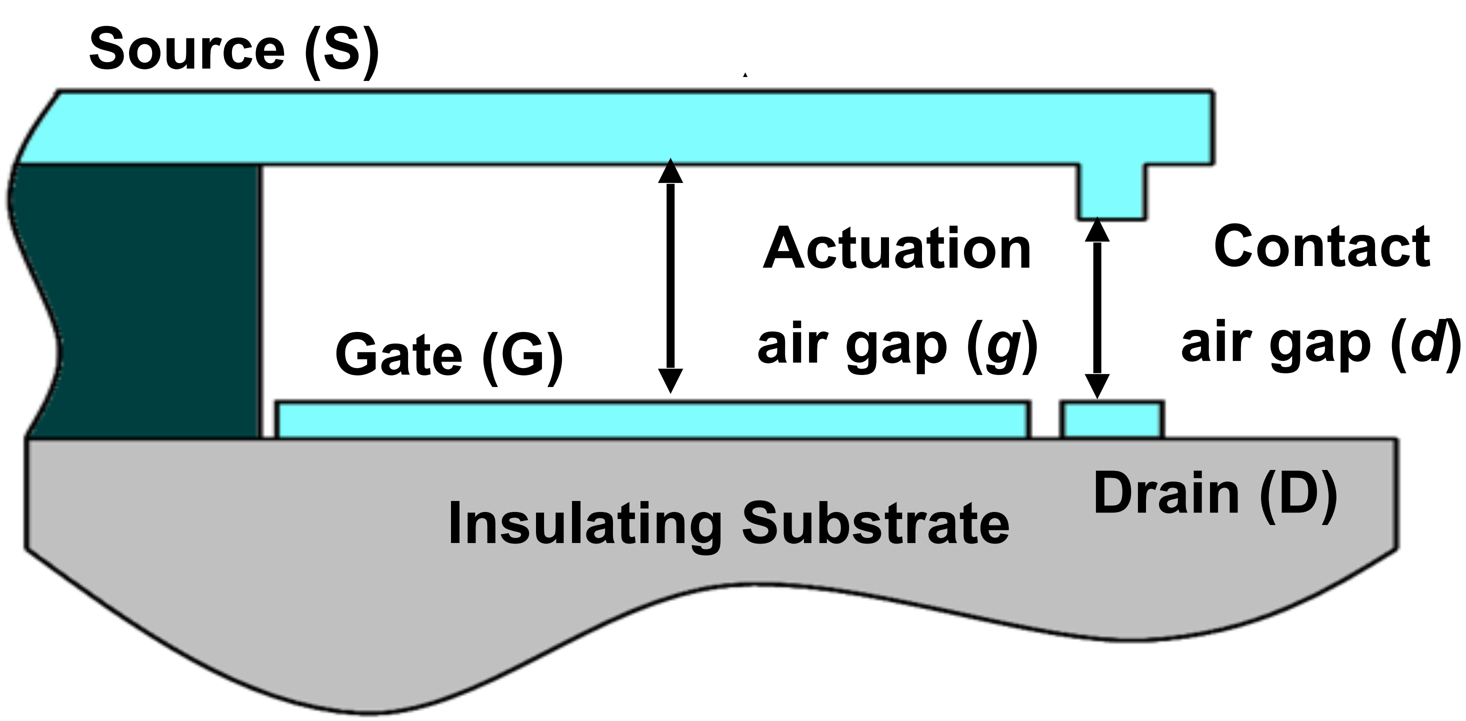

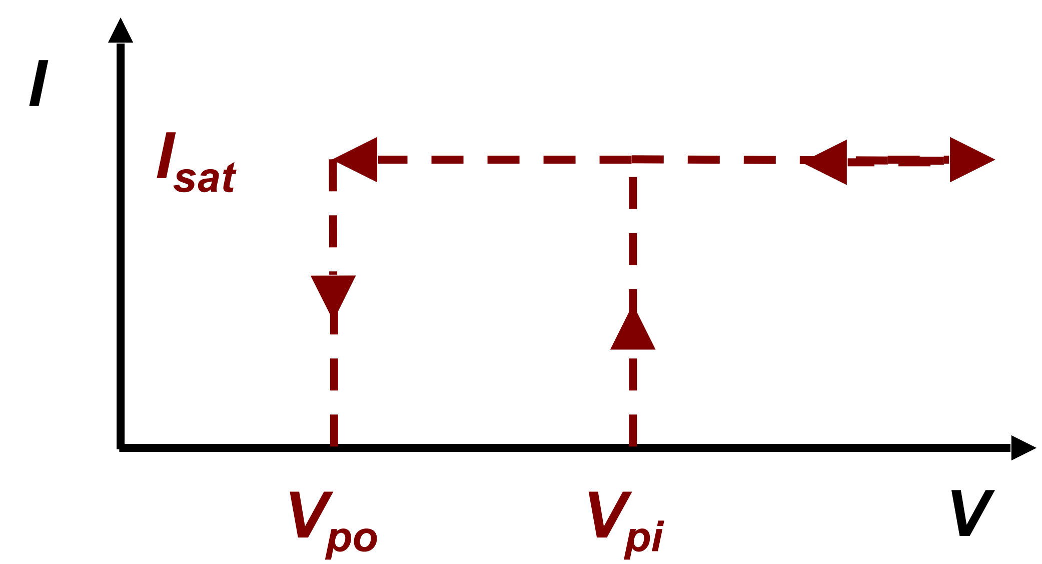

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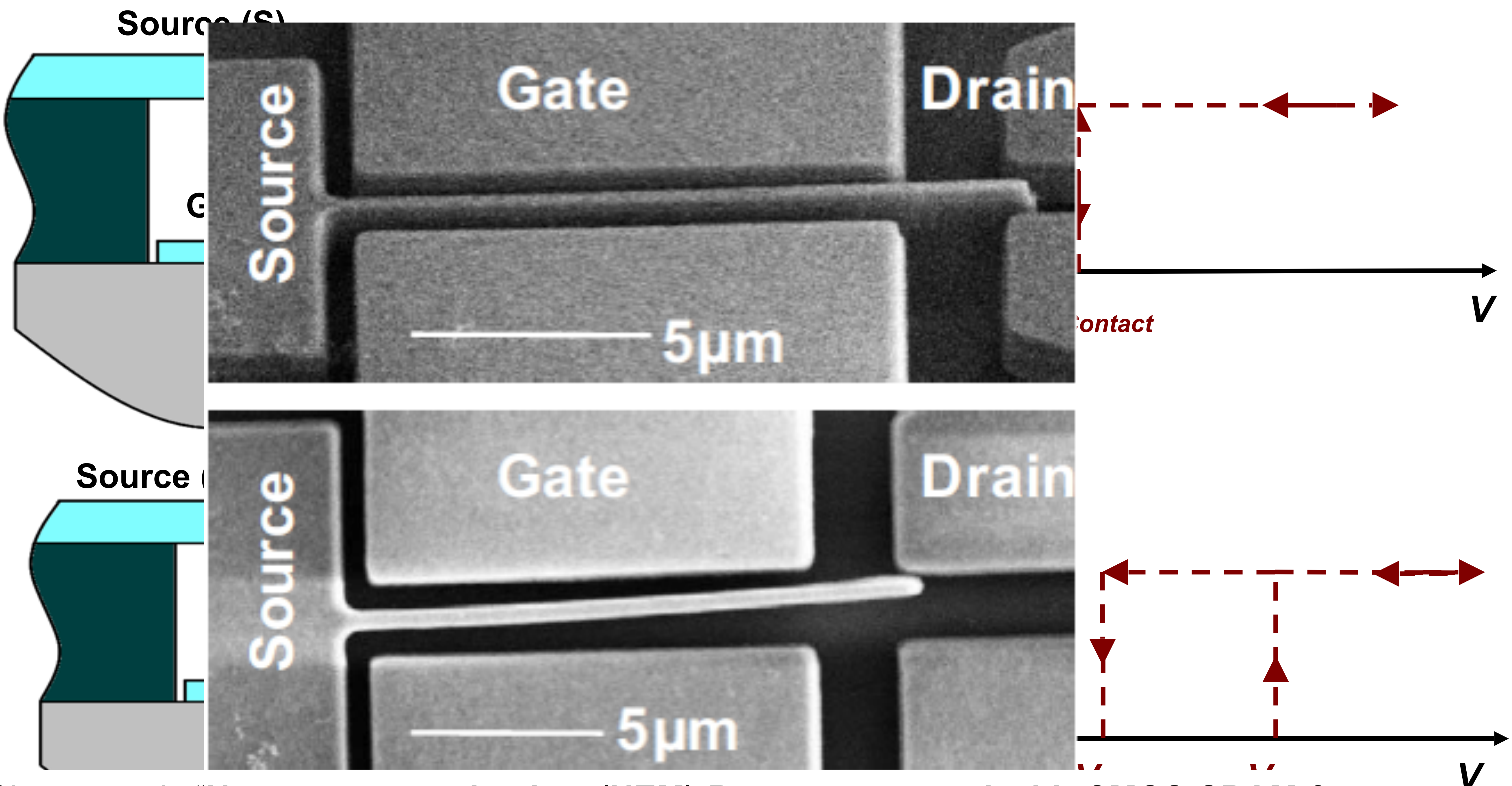

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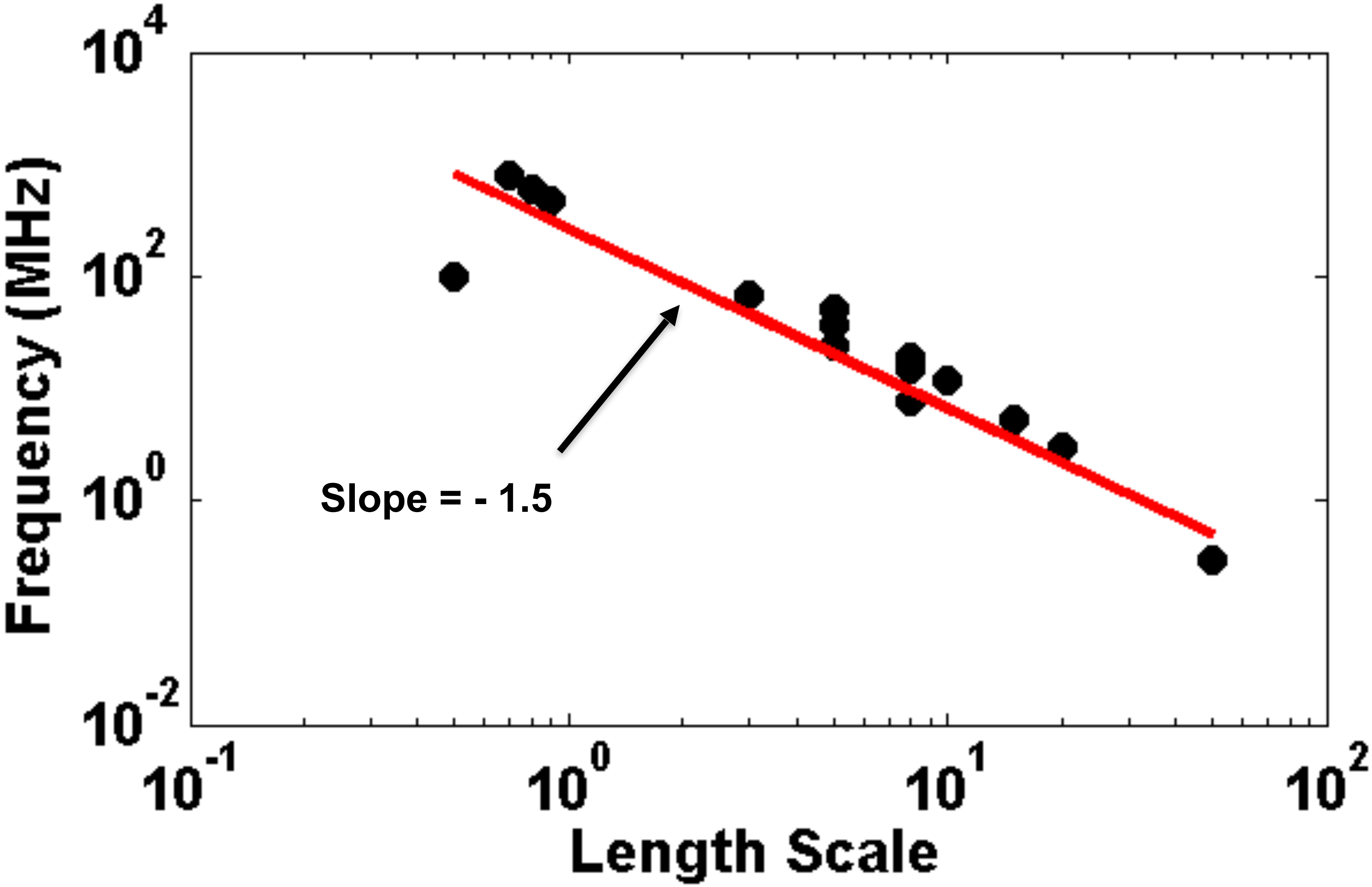

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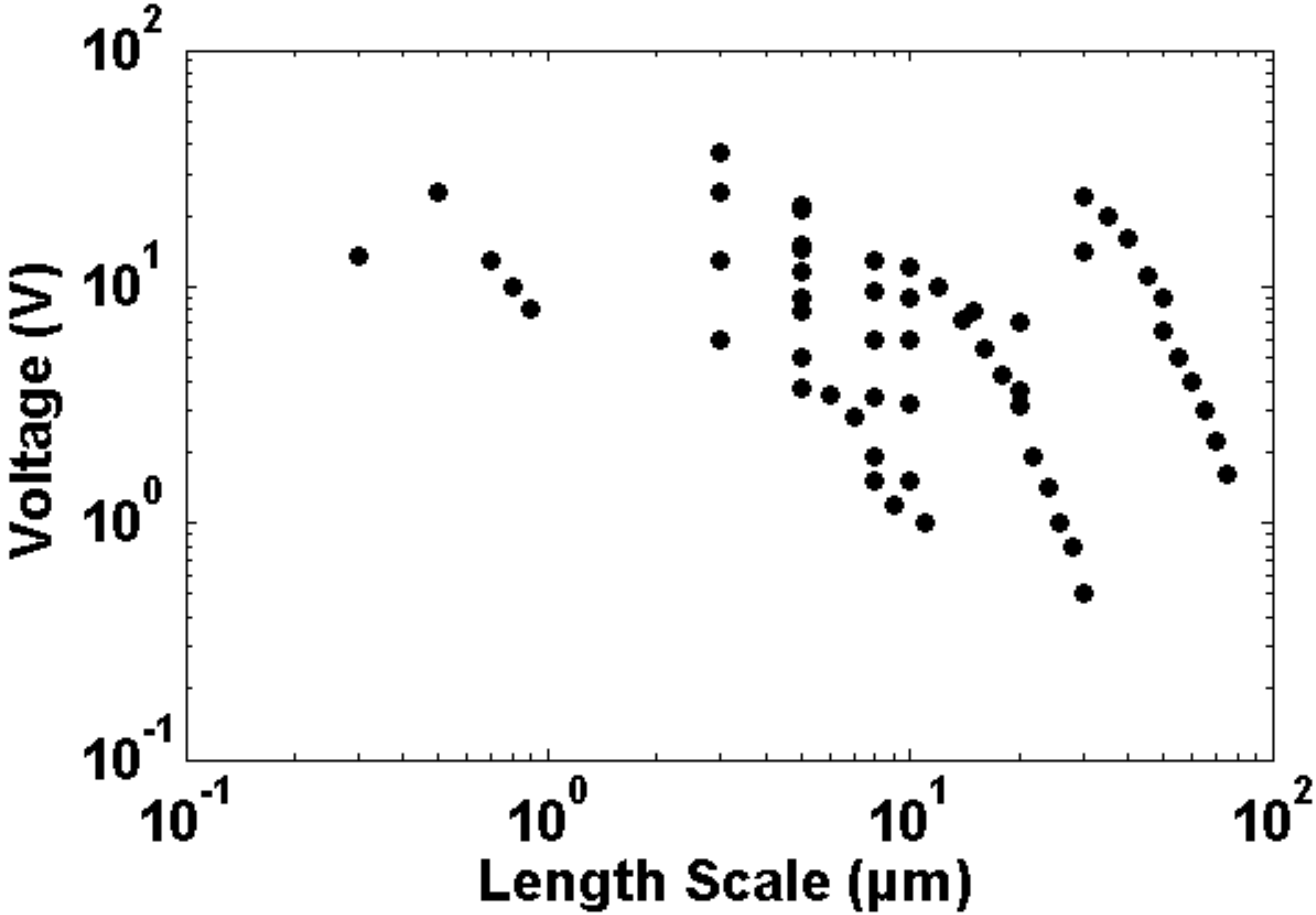

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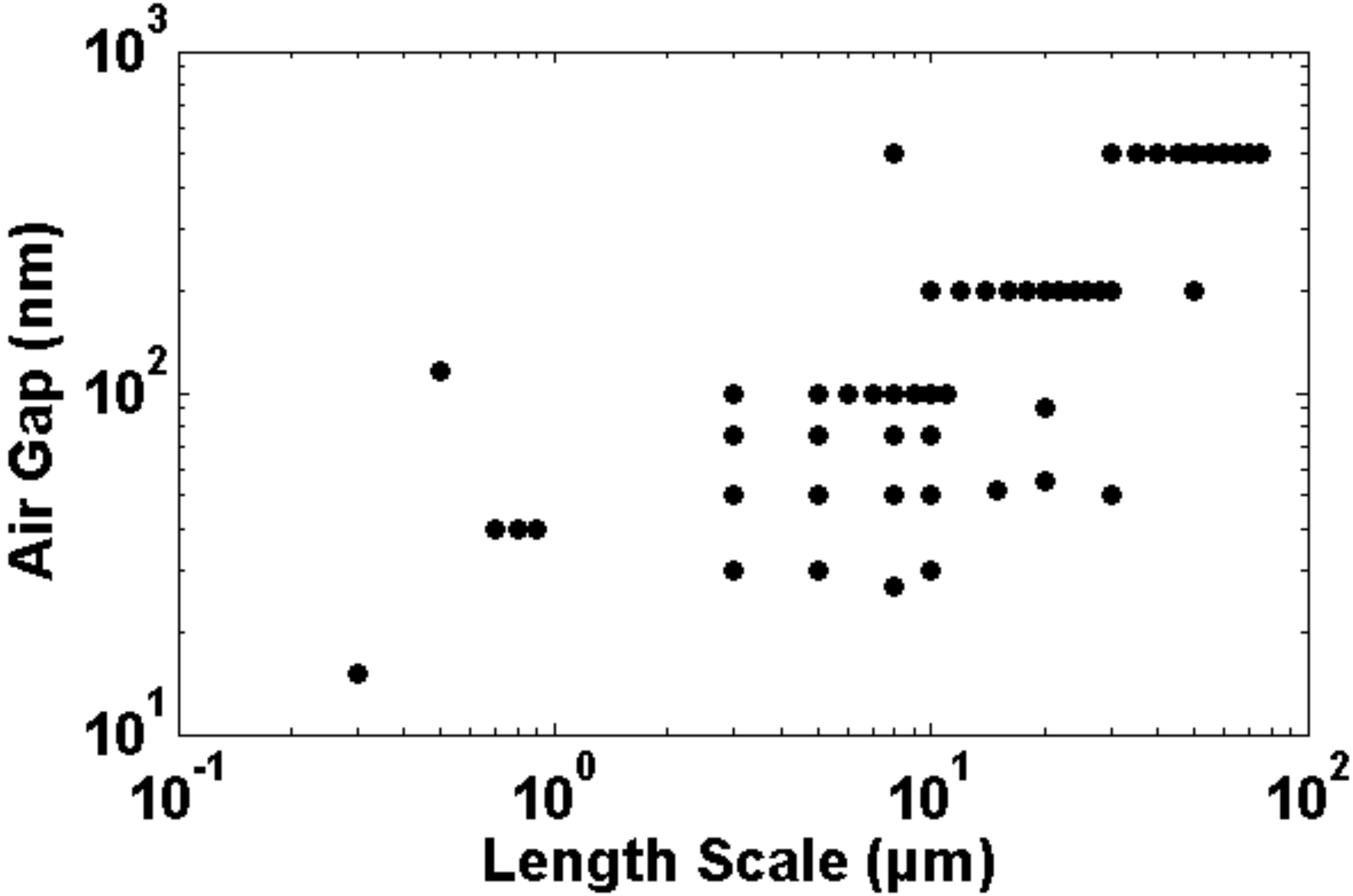

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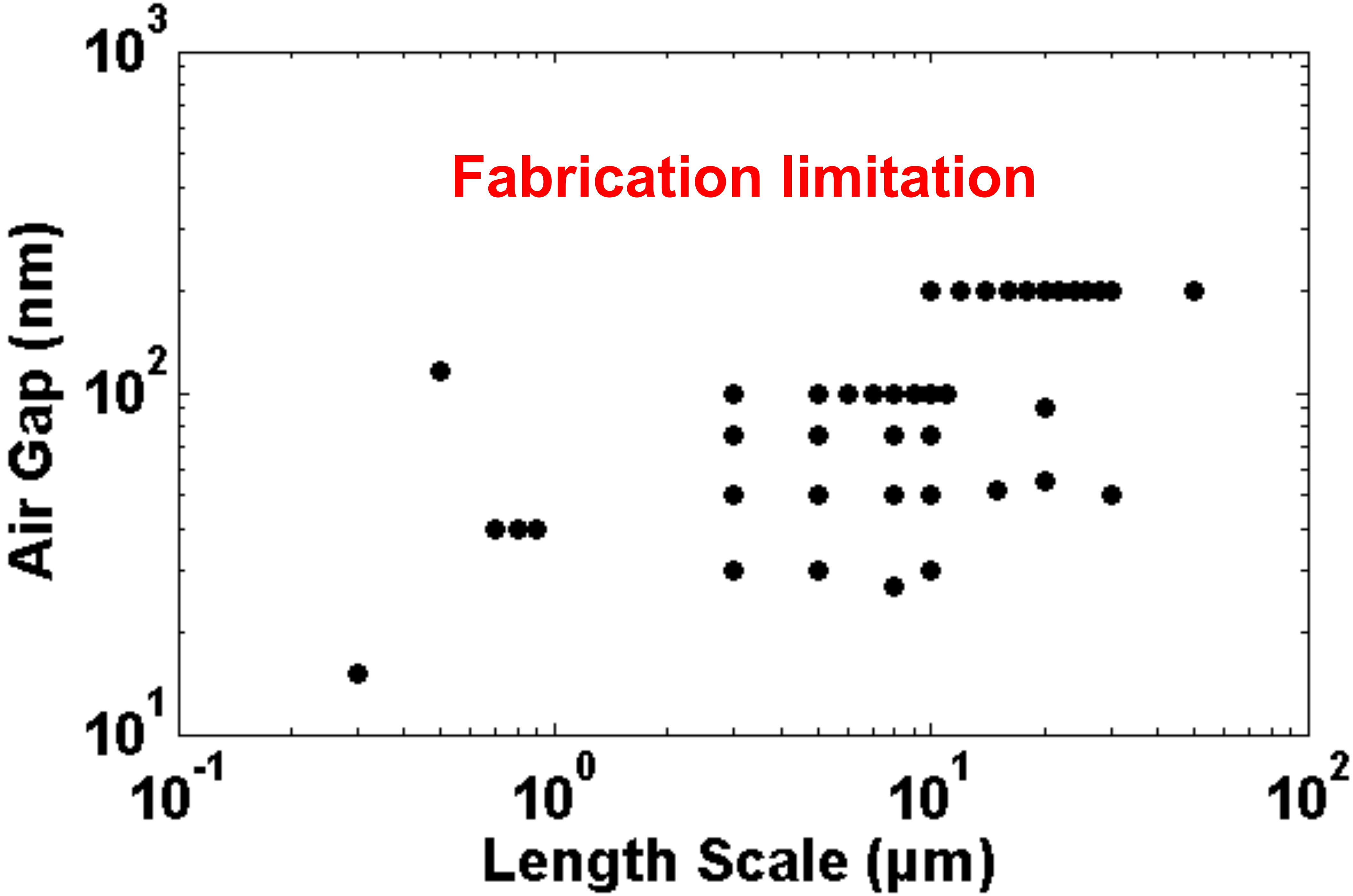

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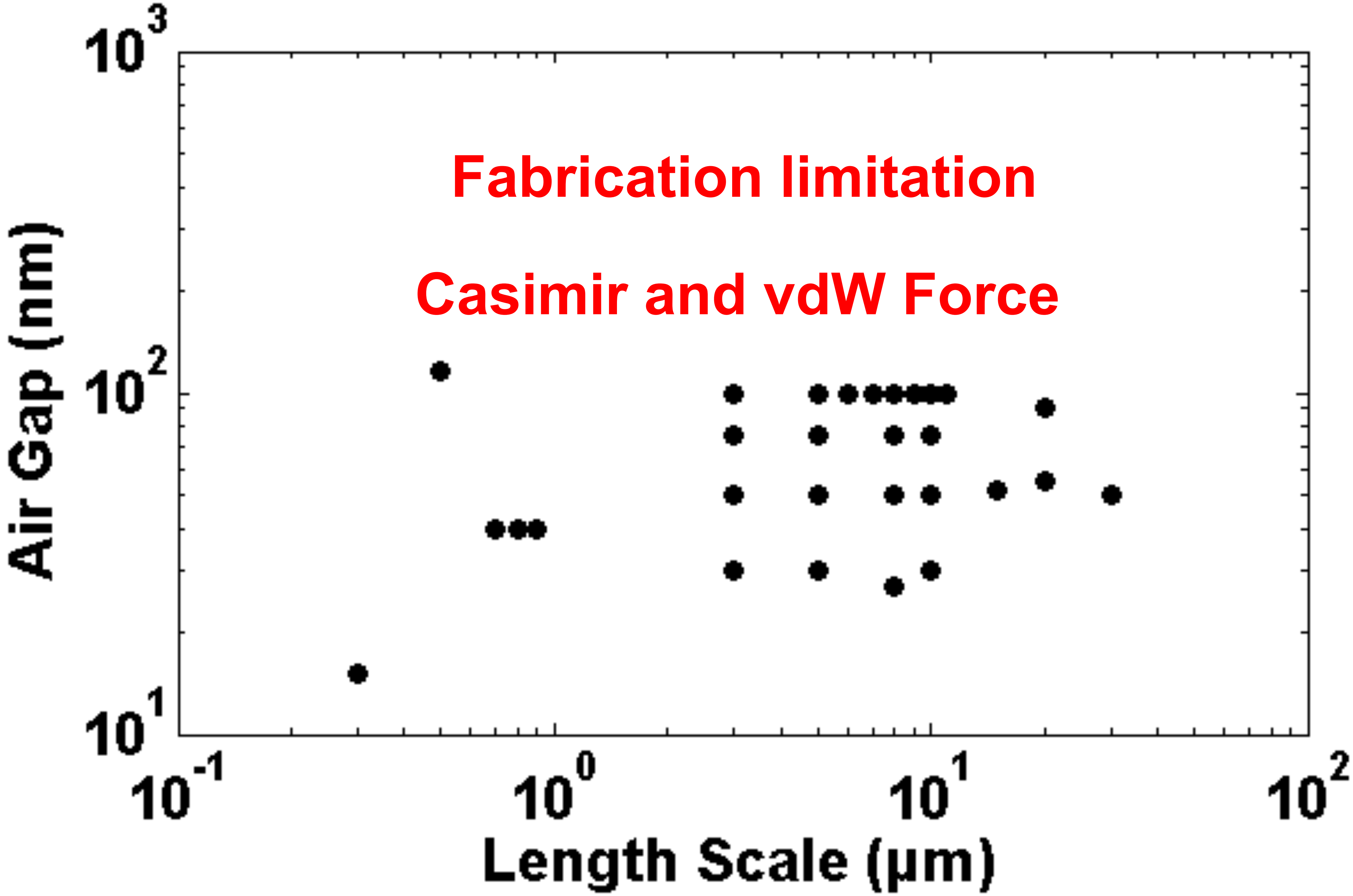

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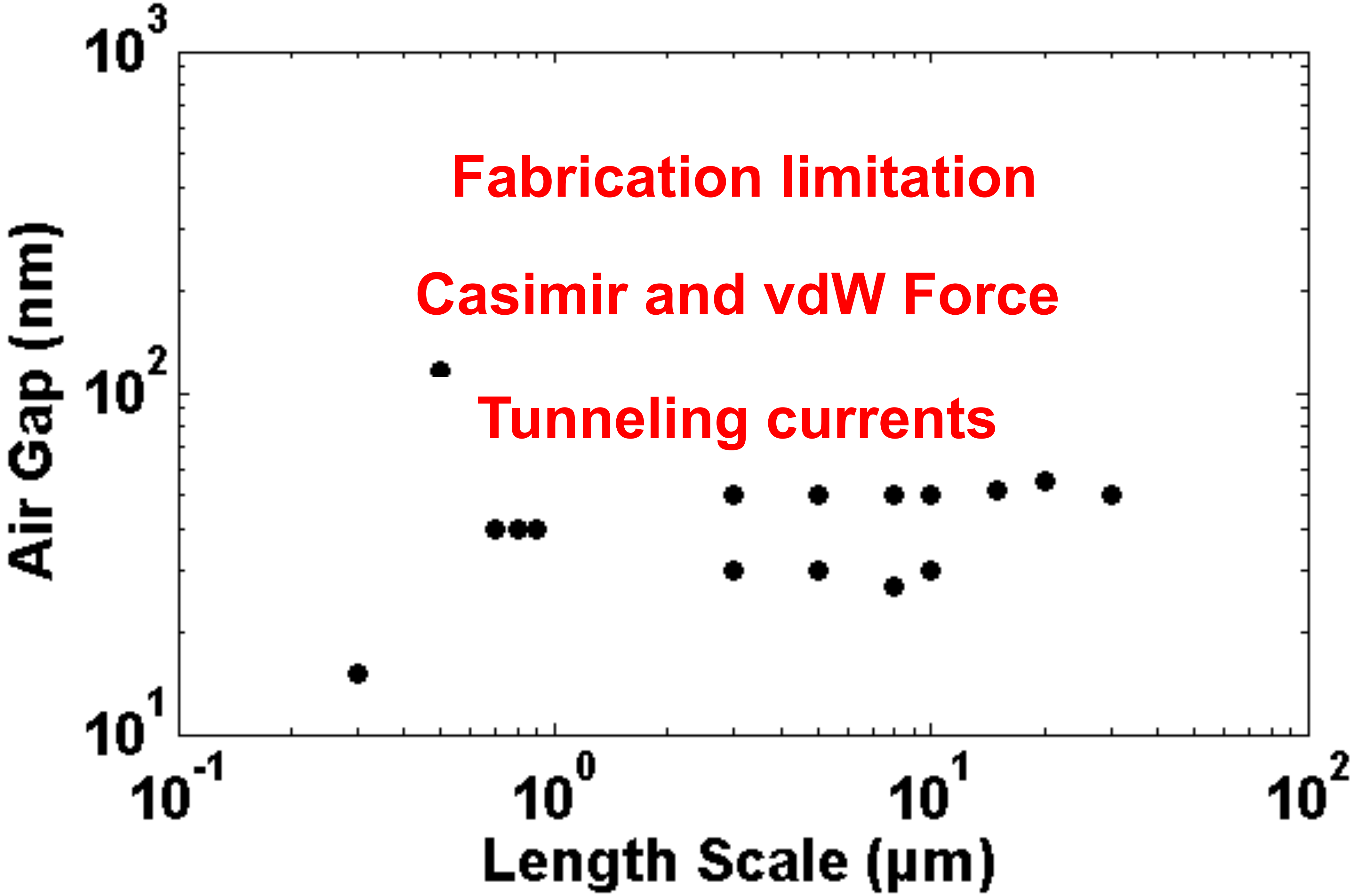

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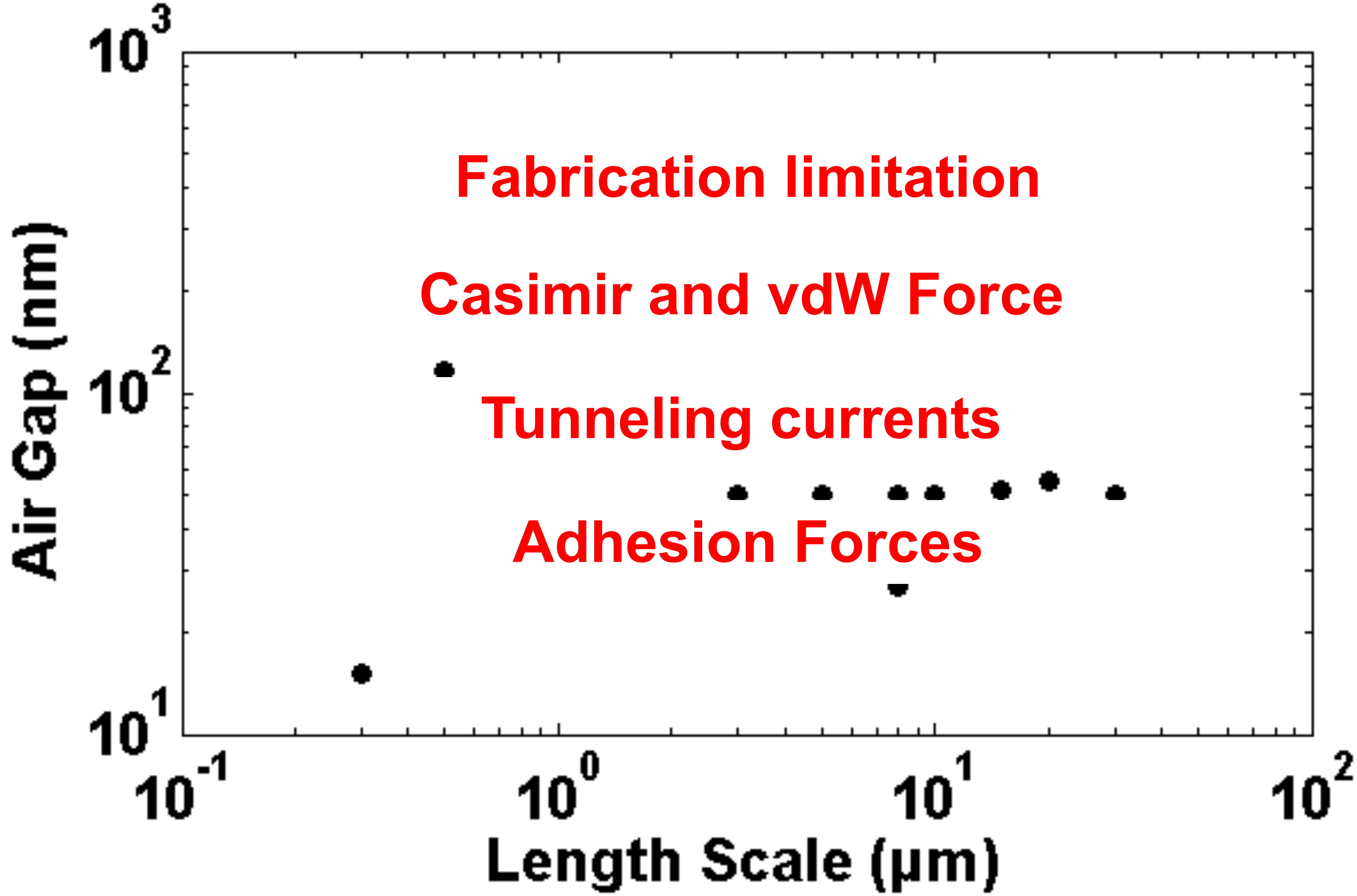

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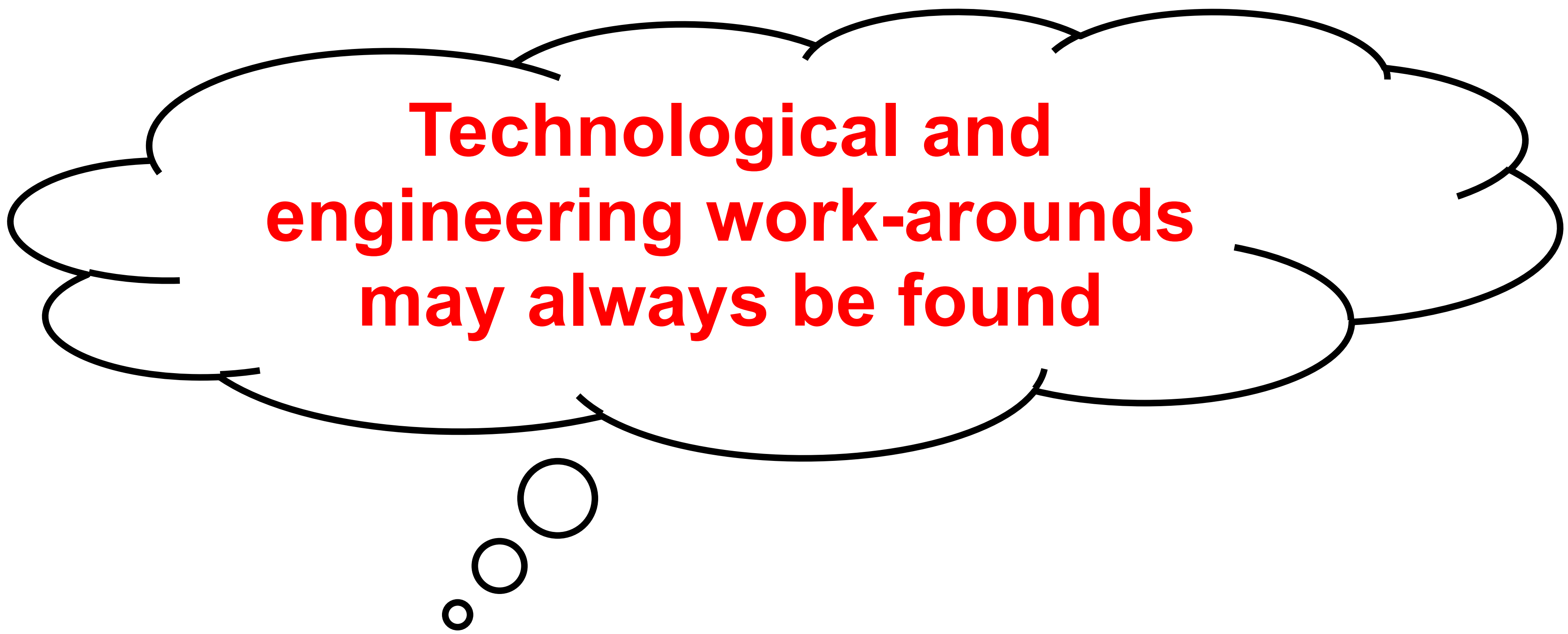

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Some possible solutions

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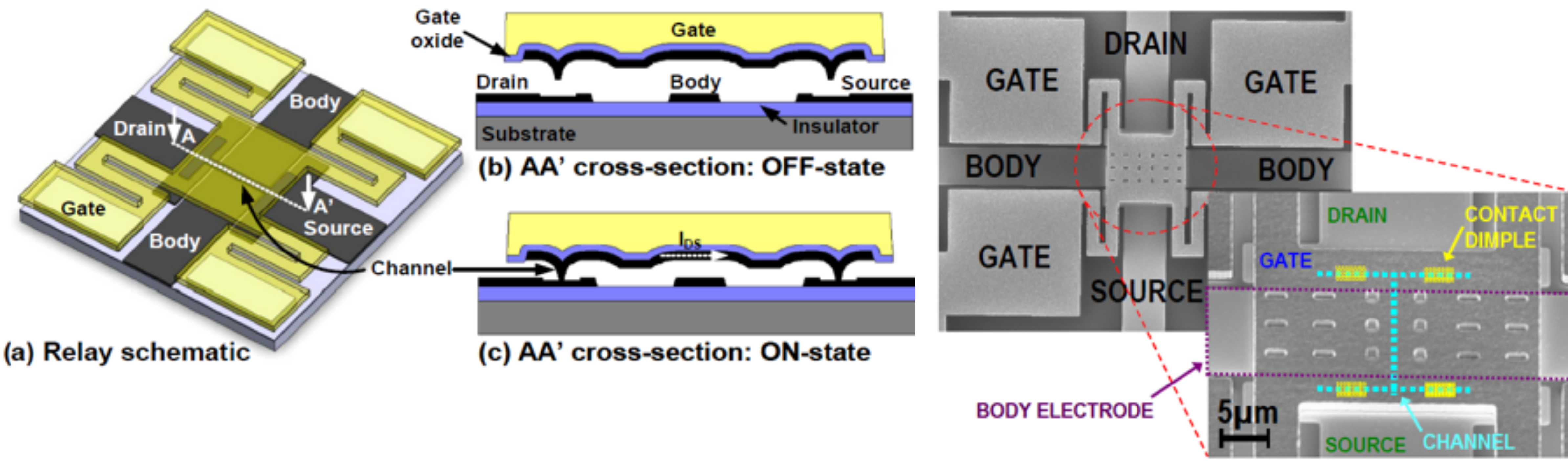

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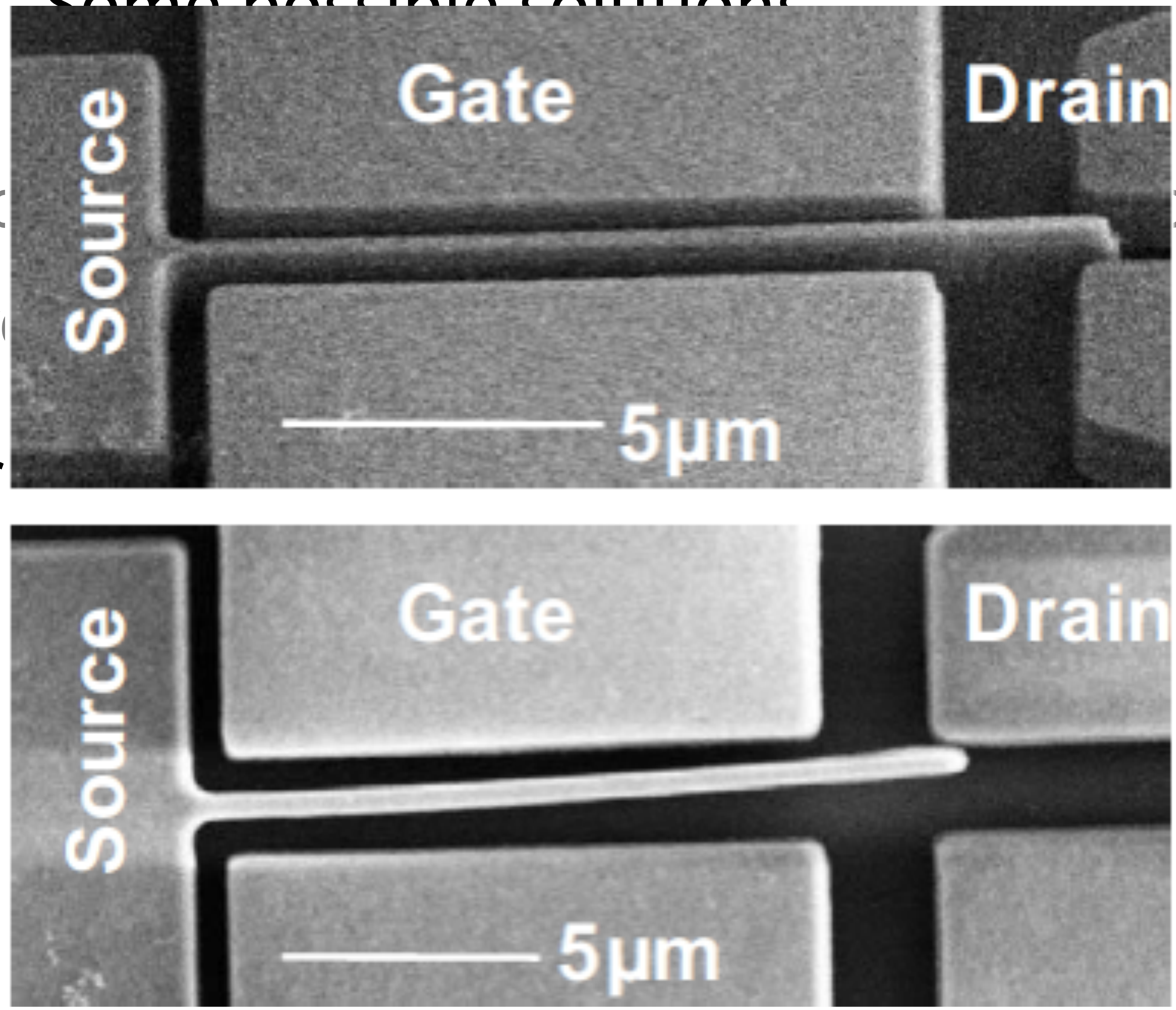

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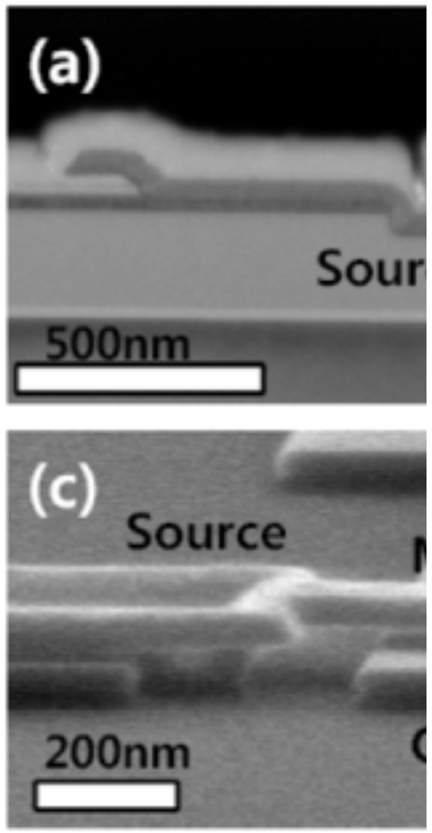

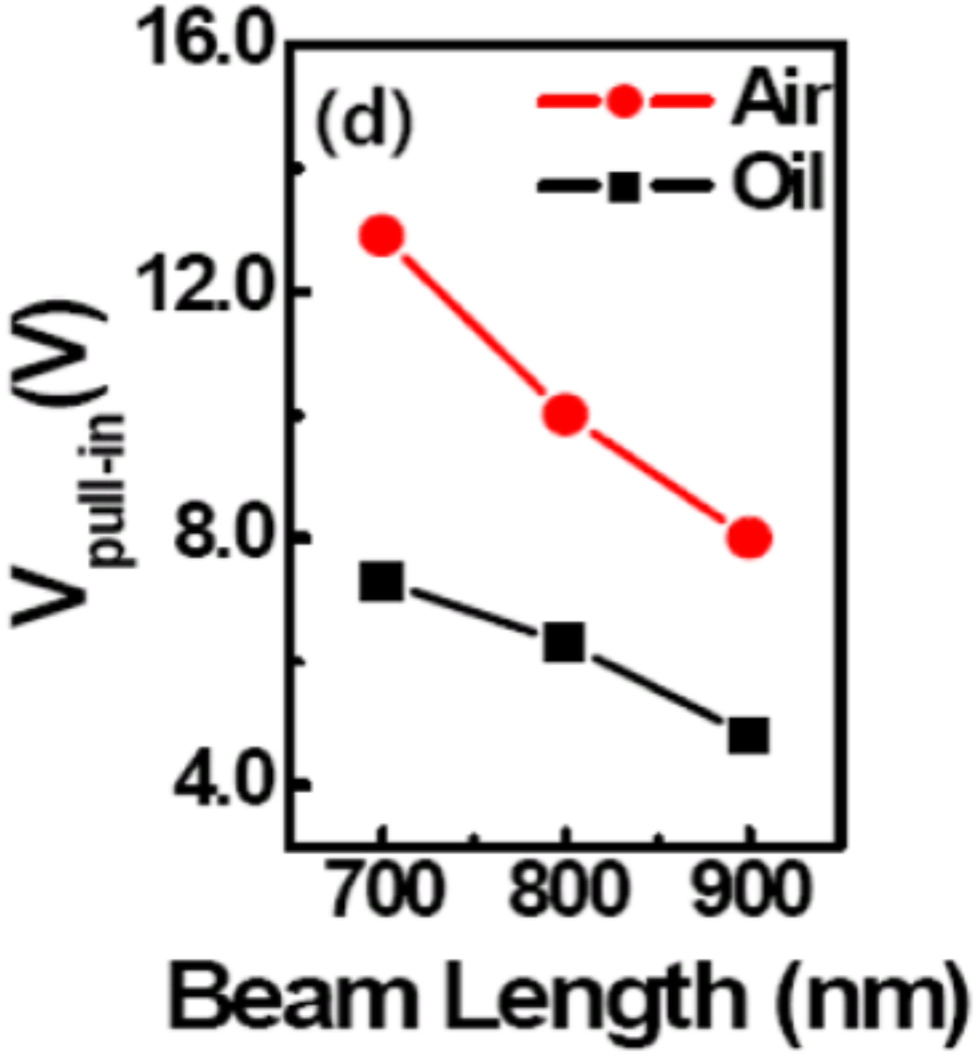

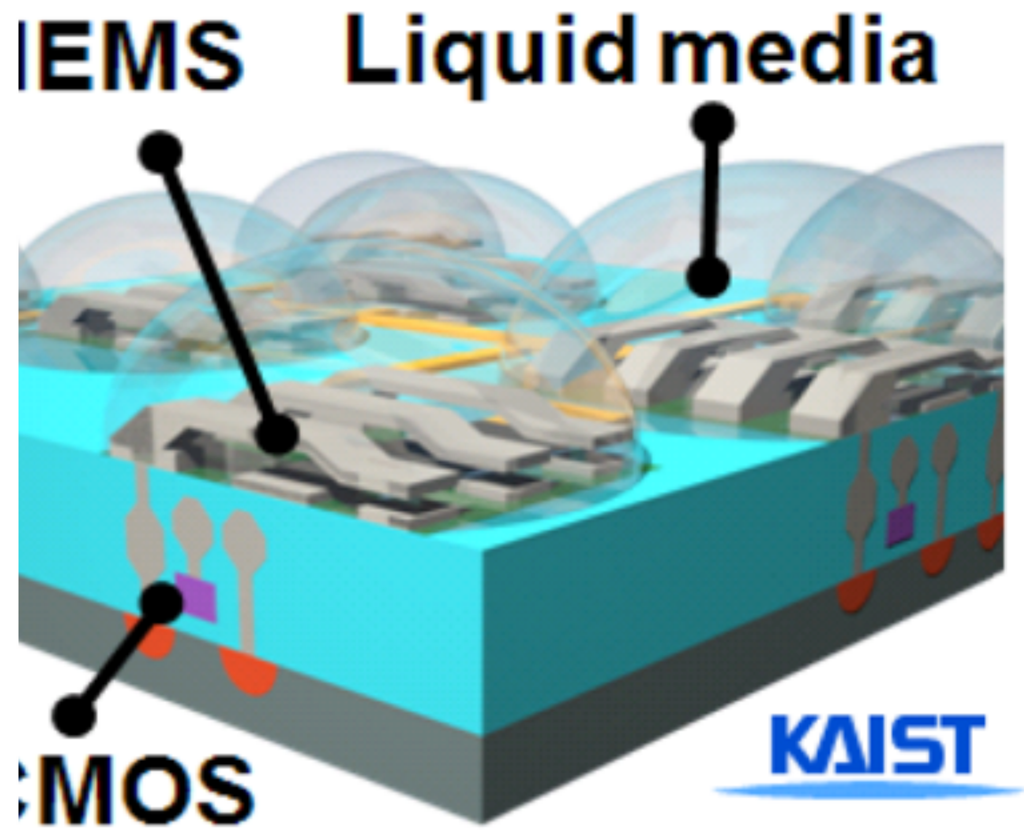

J-O Lee *et al.*, "**3-Terminal Nanoelectromechanical Switching Device in Insulating Liquid Media for Low Voltage Operation and Reliability Improvement**", IEDM 2009

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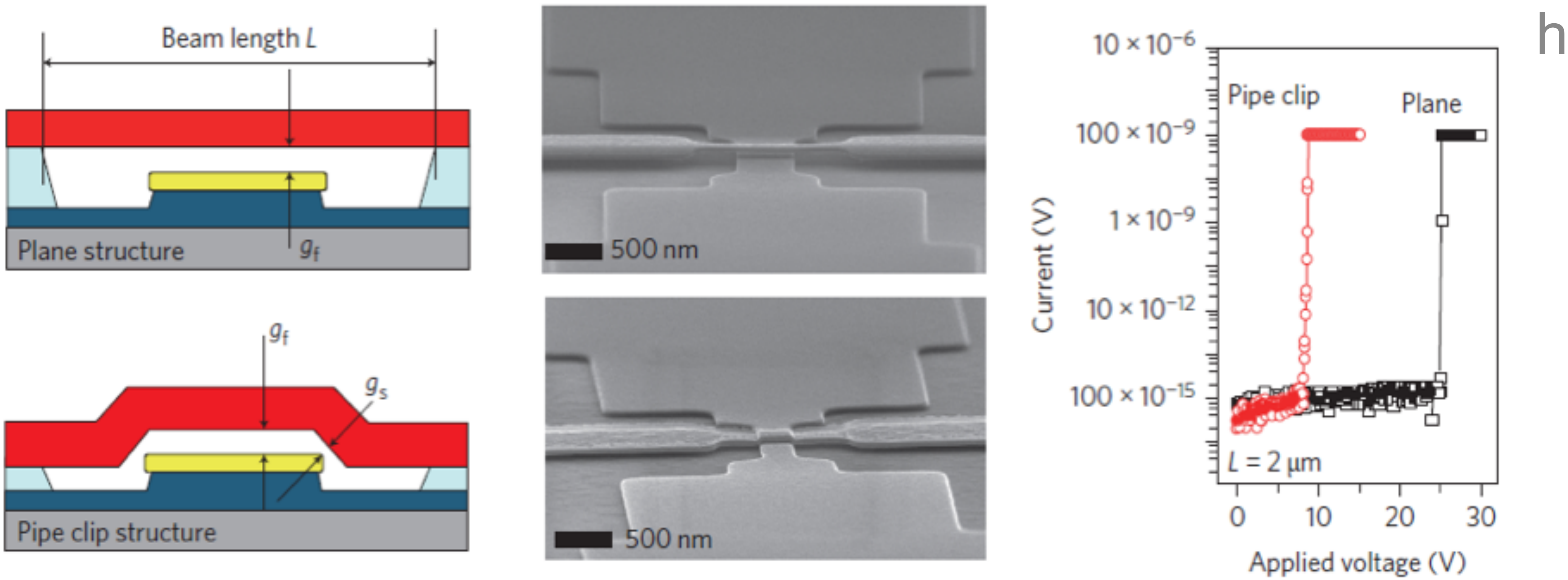

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- Innovative fabrication process
- Explore new materials and modes of operation

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NEMS-Based Adiabatic Logic Circuits
A Match Made in Heaven ?

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NEMS-Based Adiabatic Logic

Circuit Level Approach

- Sub-threshold
- Parallelism
- Power Gating
- Asynchronous
- Adiabatic

+

Device Level Approach

- SOI/ FDSOI
- FinFET
- TFET
- III-V FET
- NWFET
- CNTFET
- NEMS

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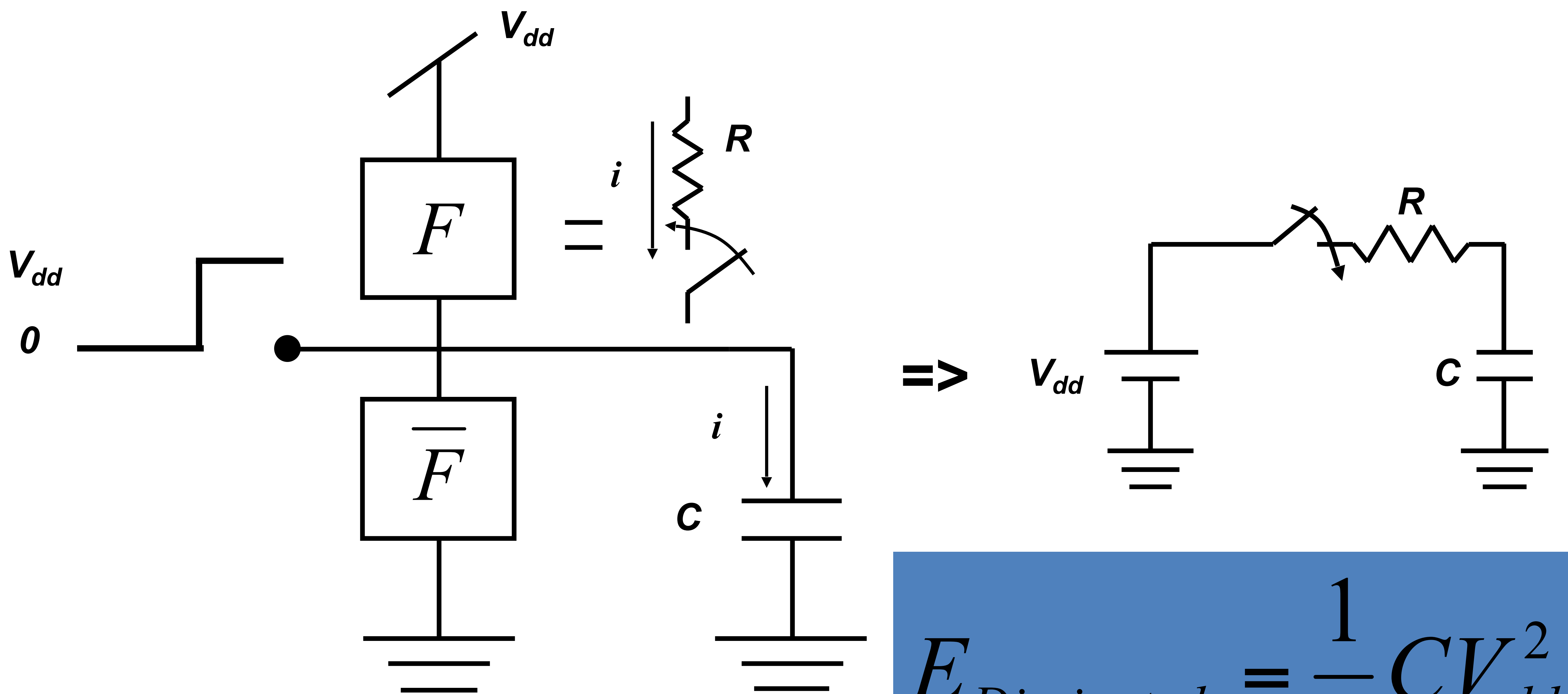
Classical Logic (*quick reminder*)



$$E_{Dissipated} = \frac{1}{2} C V_{dd}^2$$

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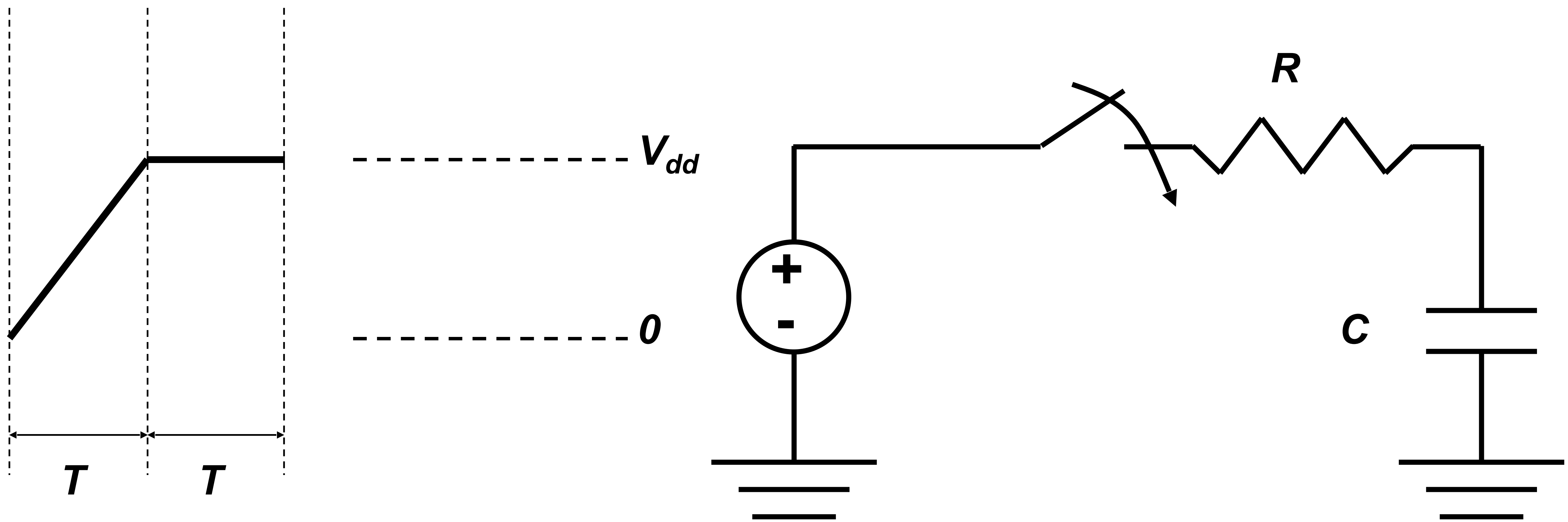
Adiabatic Charging of Capacitors



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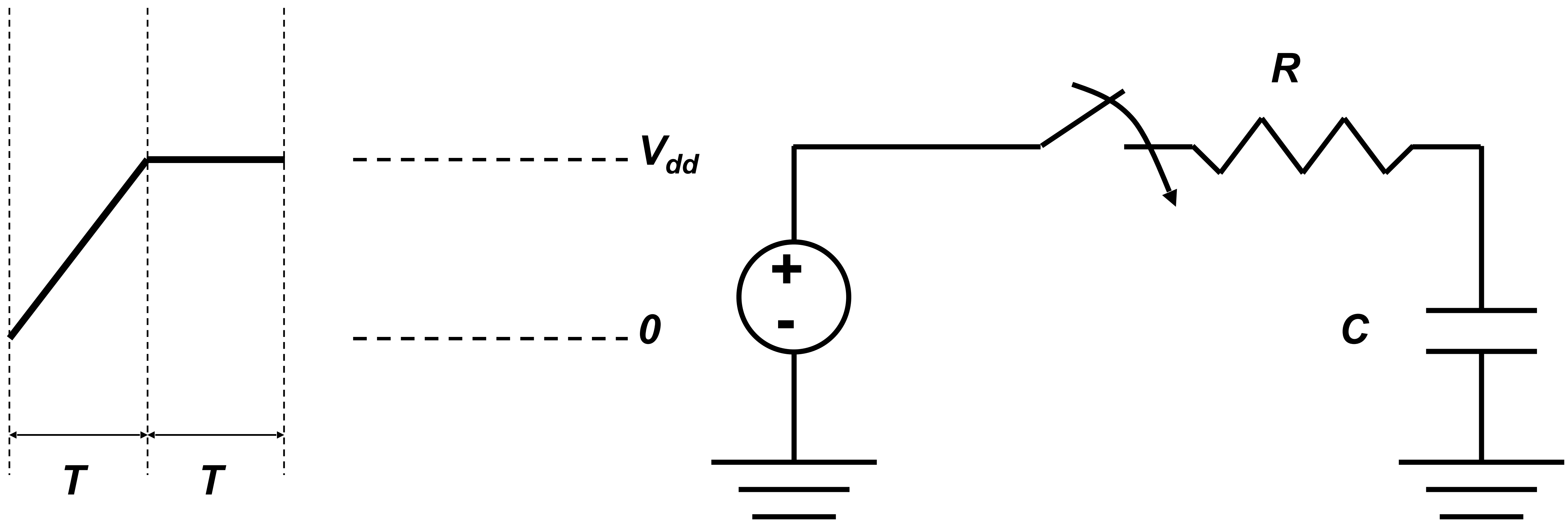

$$E_{adiabatic} \cong \frac{RC}{T} CV^2$$

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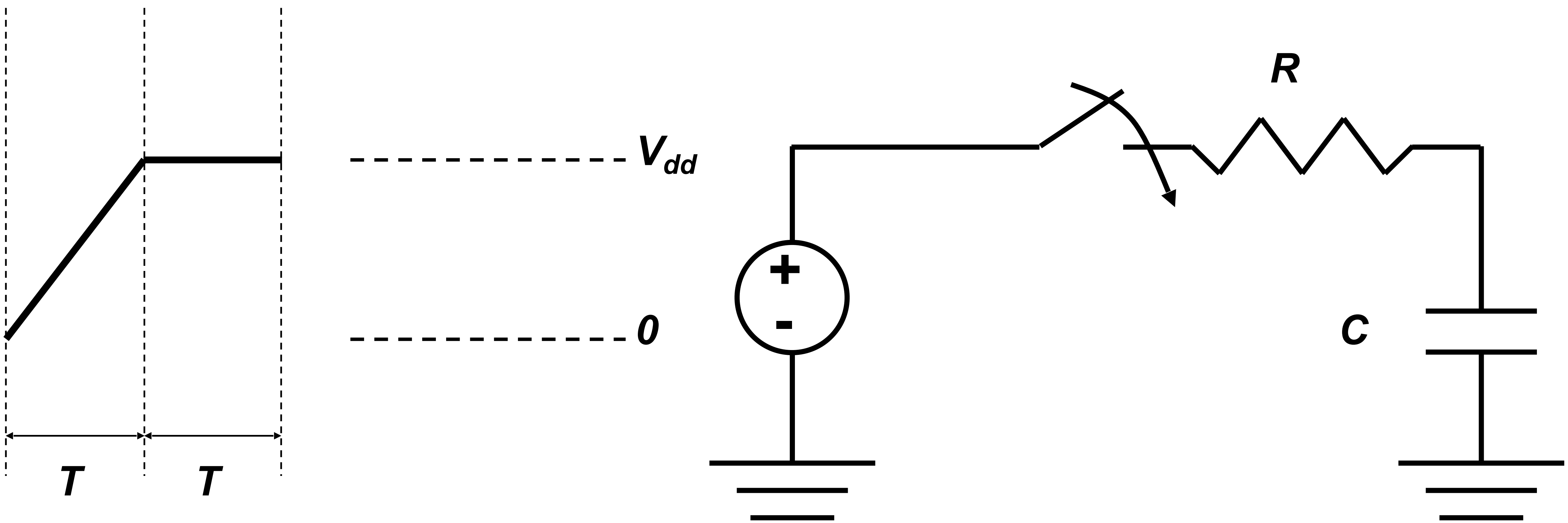

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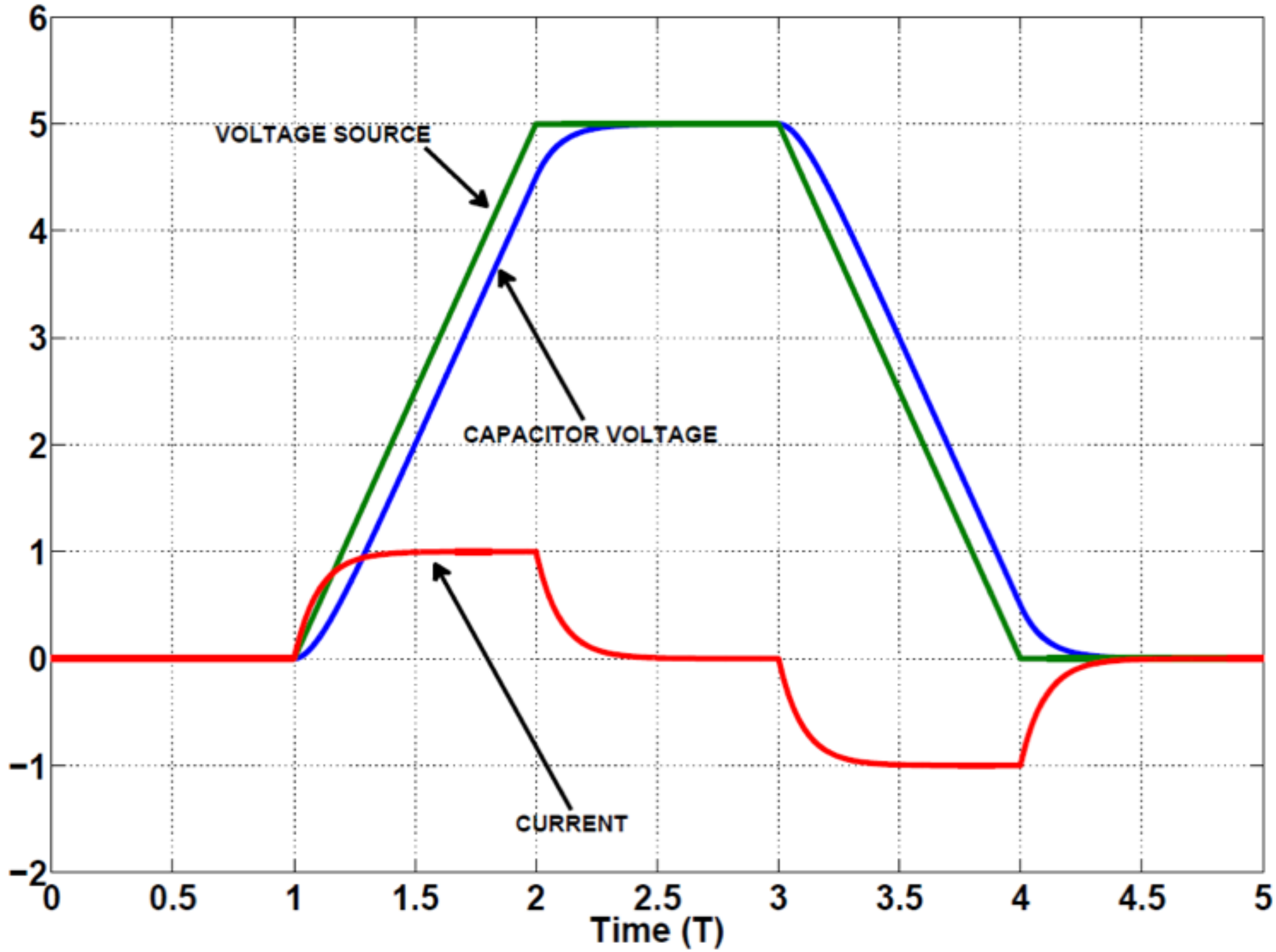

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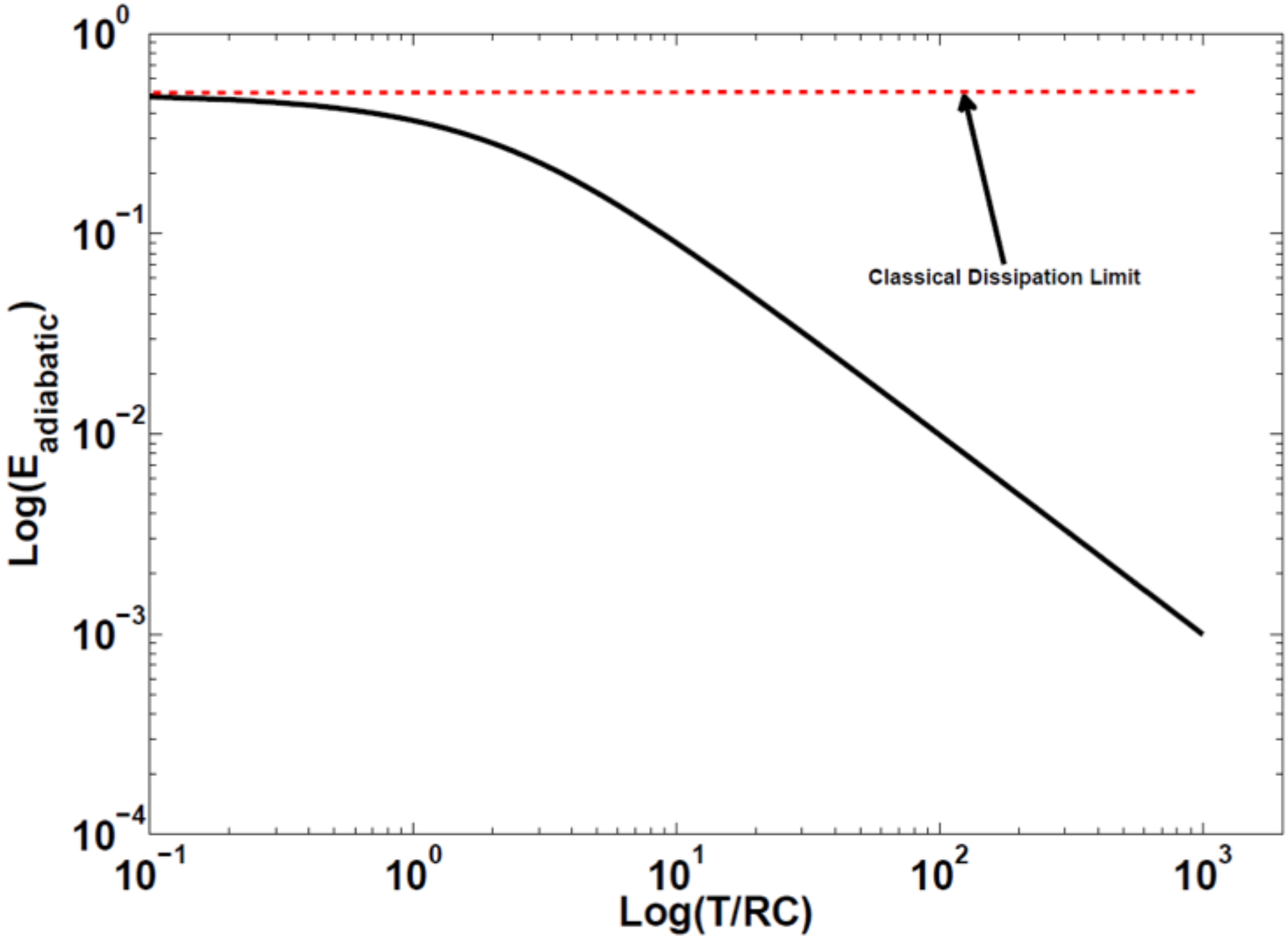

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REMEMBER

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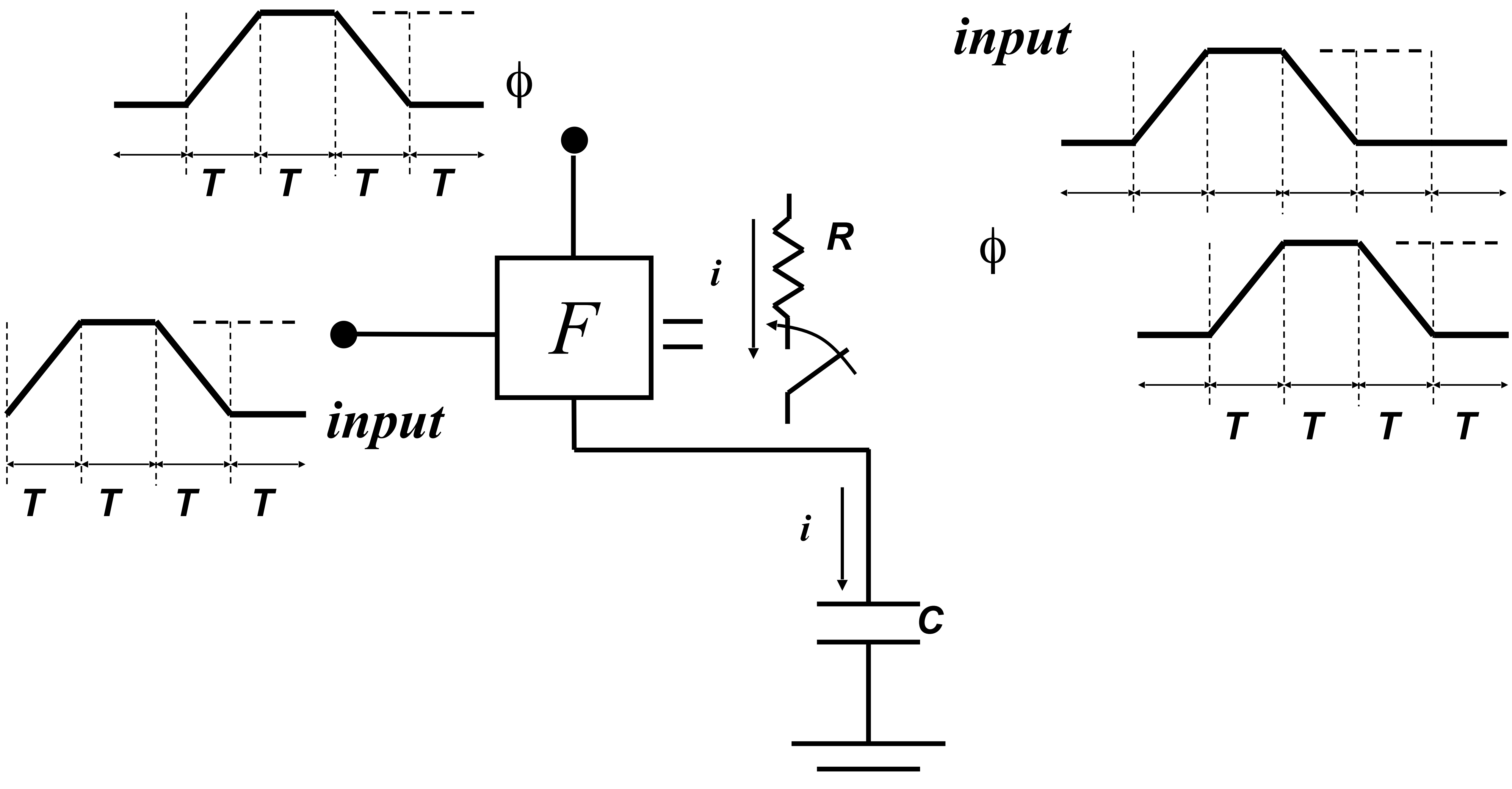
Adiabatic Logic



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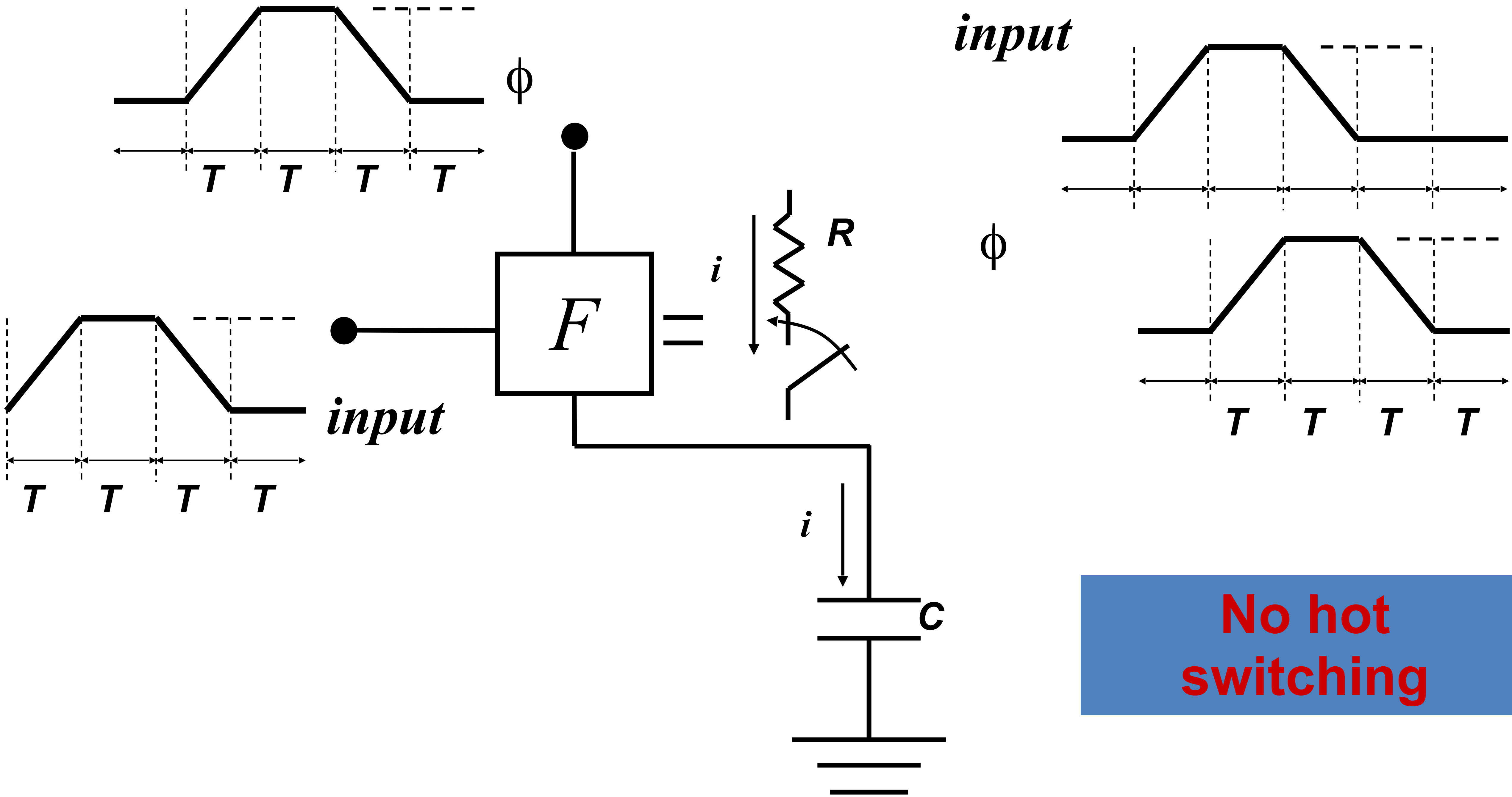

No hot switching

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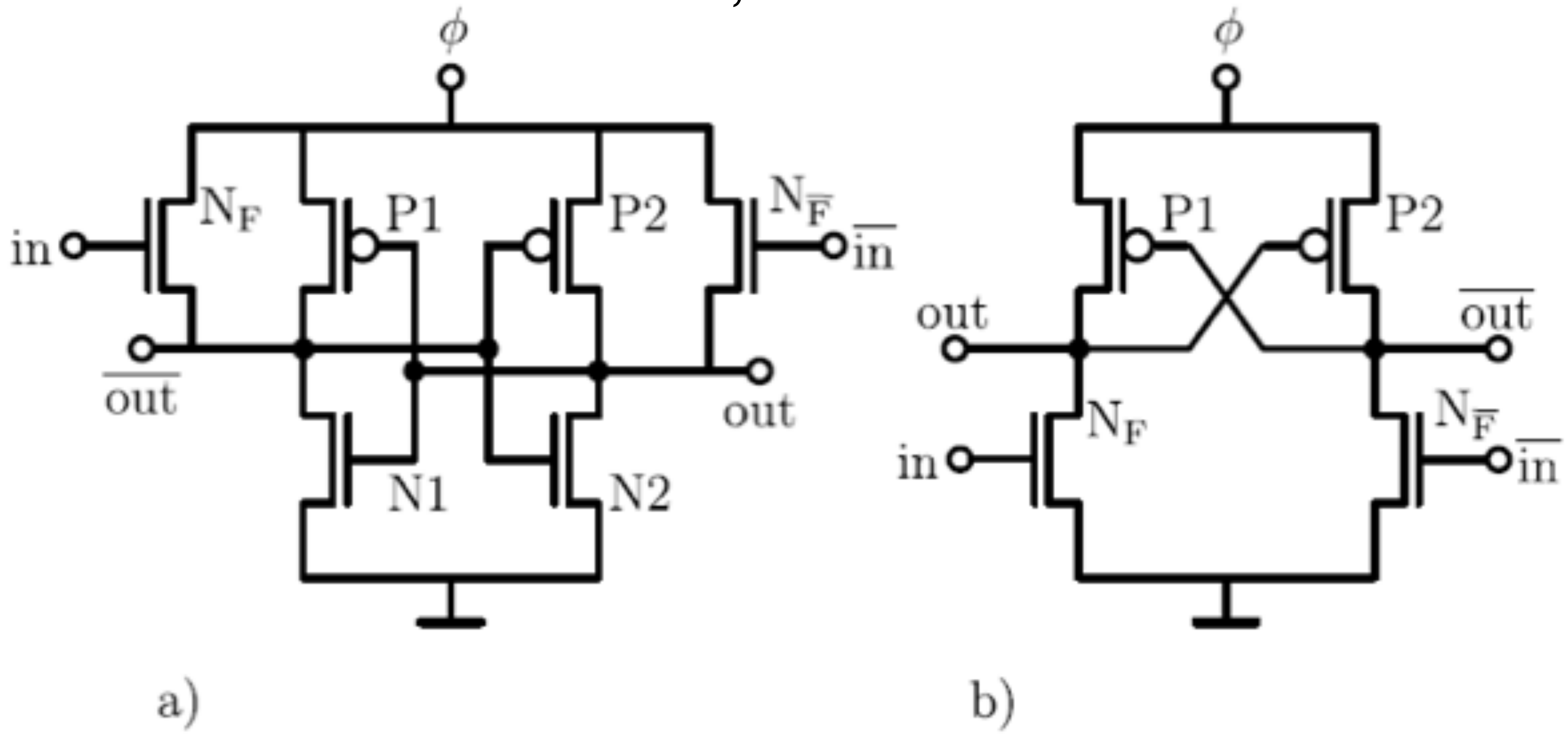
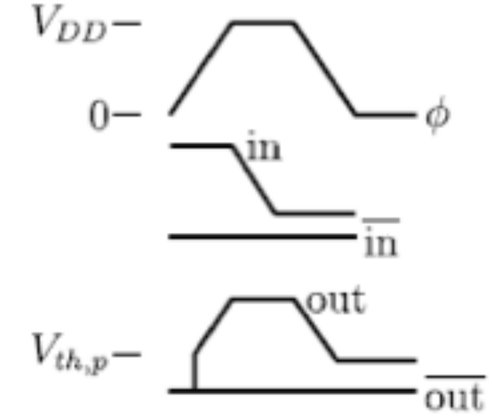
CMOS Adiabatic Logic

P. Teichmann, 2012



Inverter circuit in the (**a**) PFAL and (**b**) ECRL family



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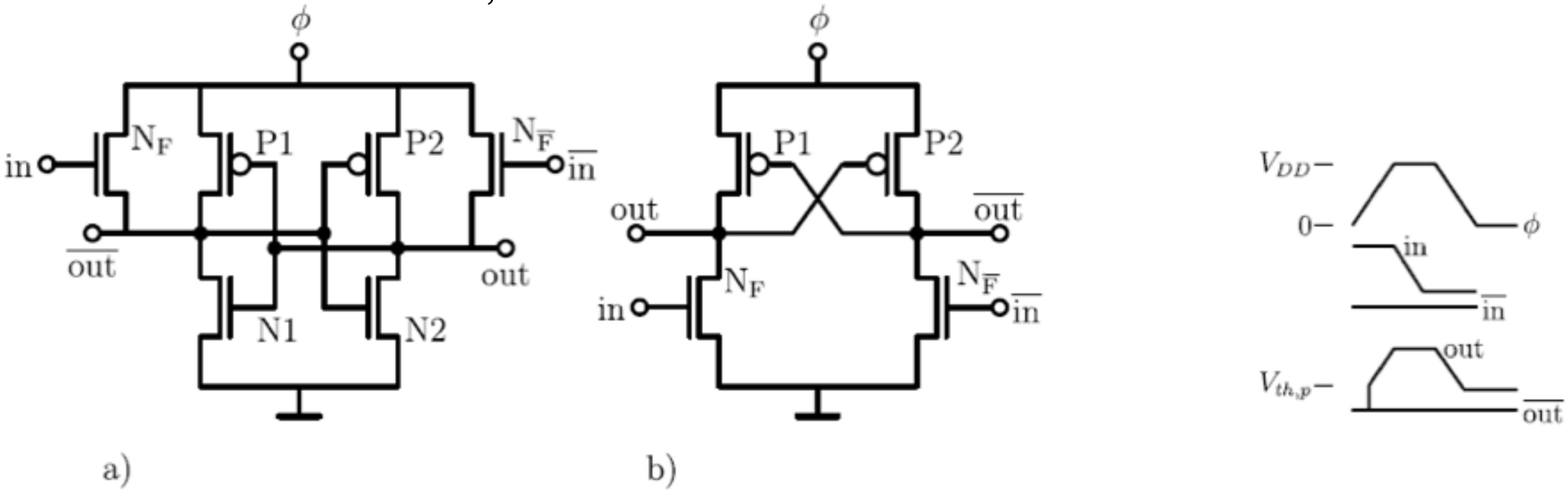

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Adiabatic

Non-Adiabatic

Static

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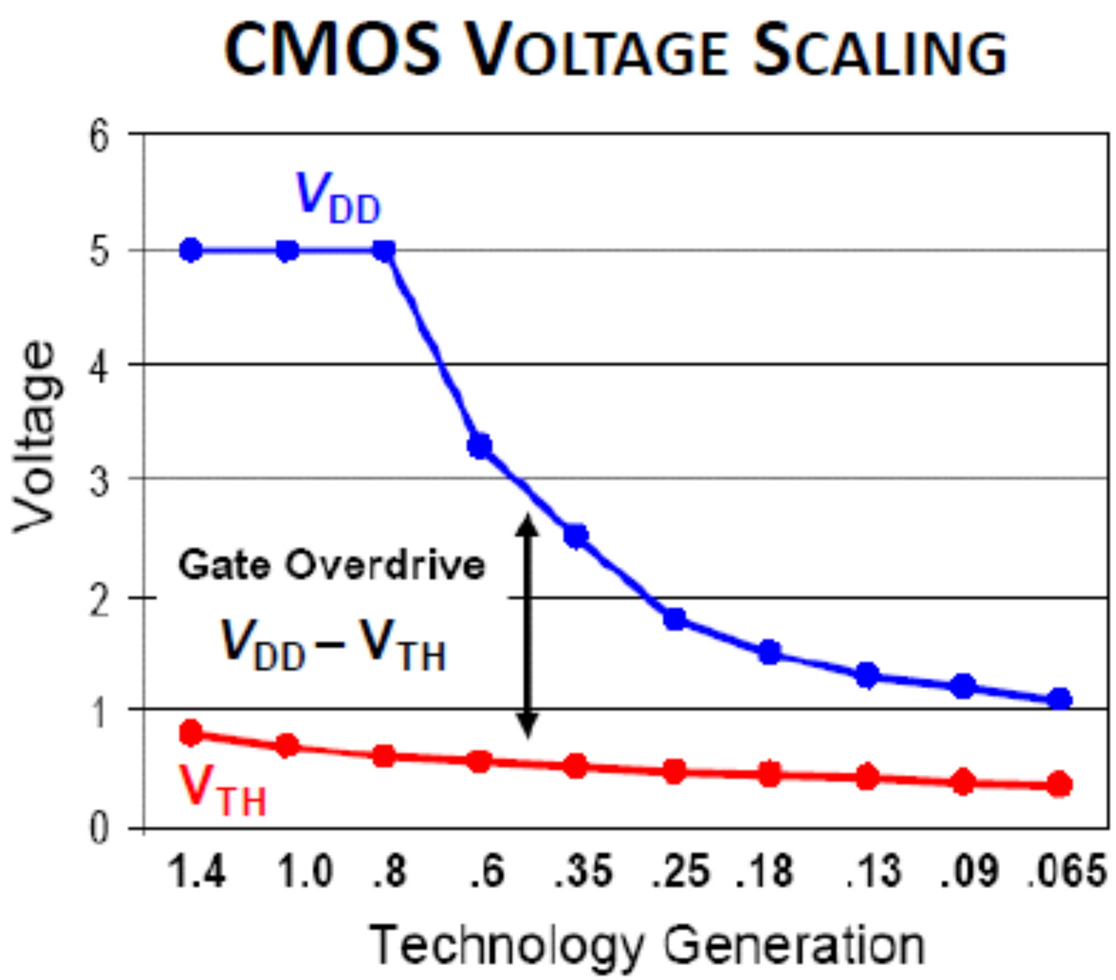
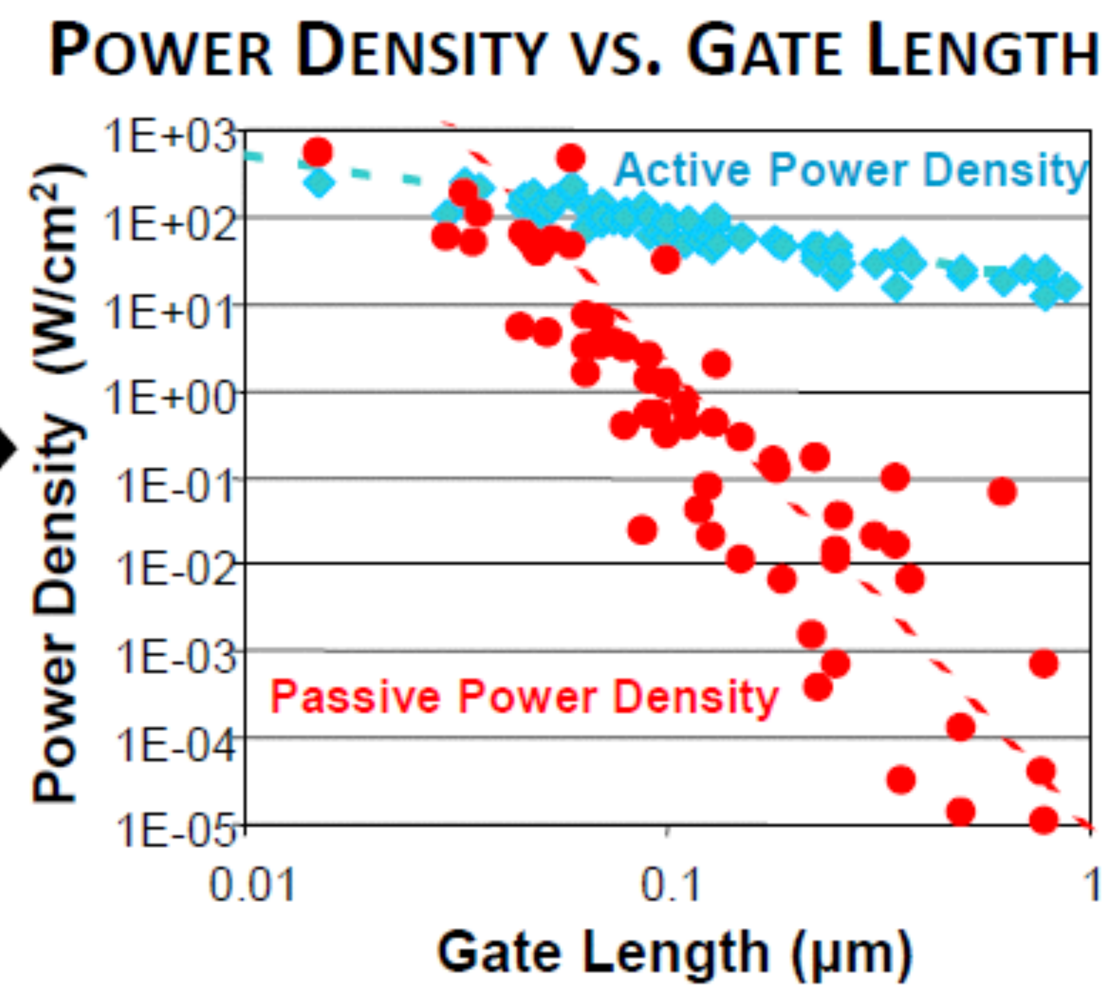


Source: P. Packan (Intel), 2007 IEDM Short Course



Source: B. Meyerson (IBM) Semico Conf., January 2004

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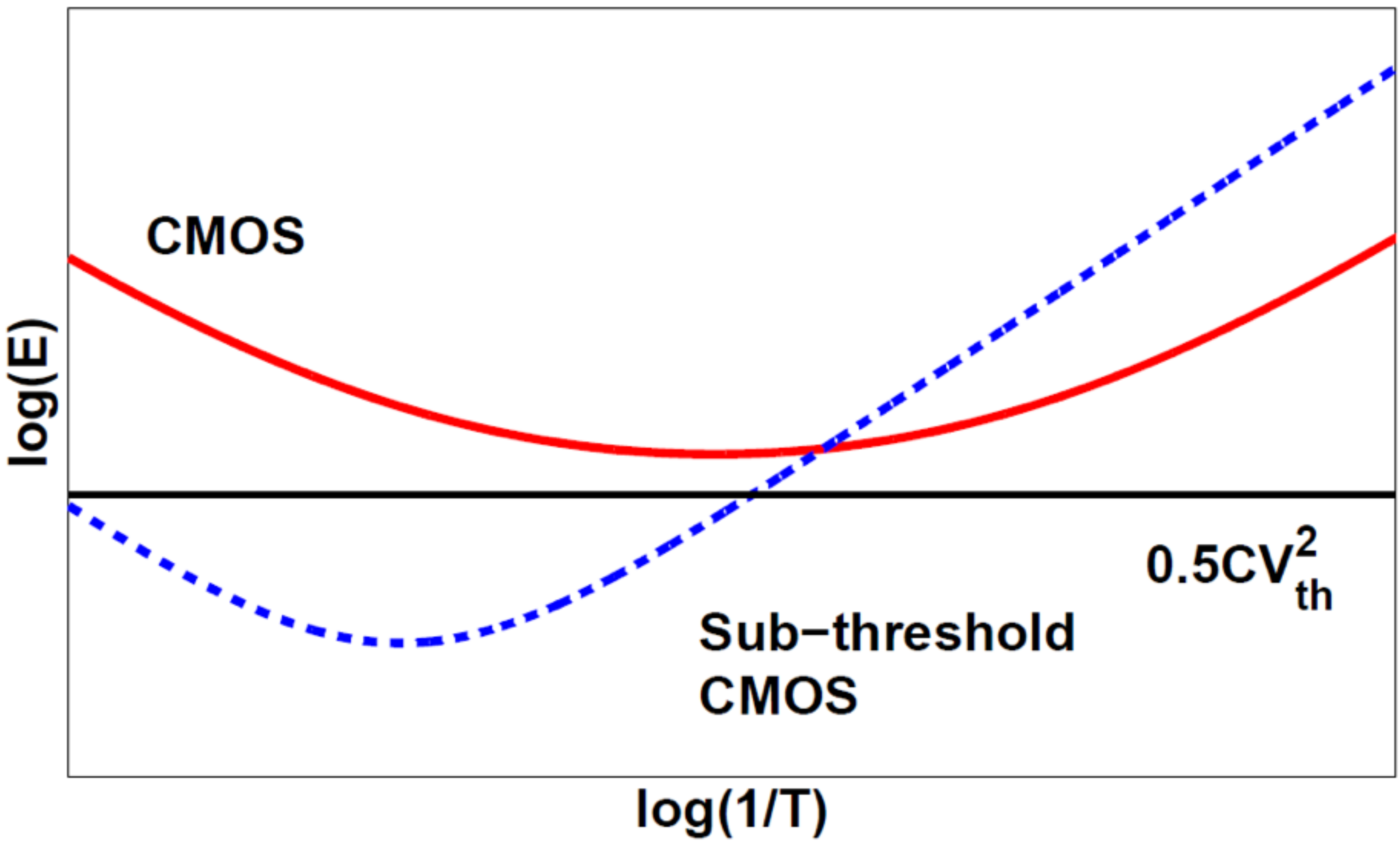
Slide courtesy of S. Houri - HOURI S., et al. Limits of CMOS Technology and Interest of NEMS Relays for Adiabatic Logic Applications. 2015.

CMOS Adiabatic Logic



Slide courtesy of S. Houri - HOURI S., et al. Limits of CMOS Technology and Interest of NEMS Relays for Adiabatic Logic Applications. 2015.

Why NEMS-Based Adiabatic Logic ?

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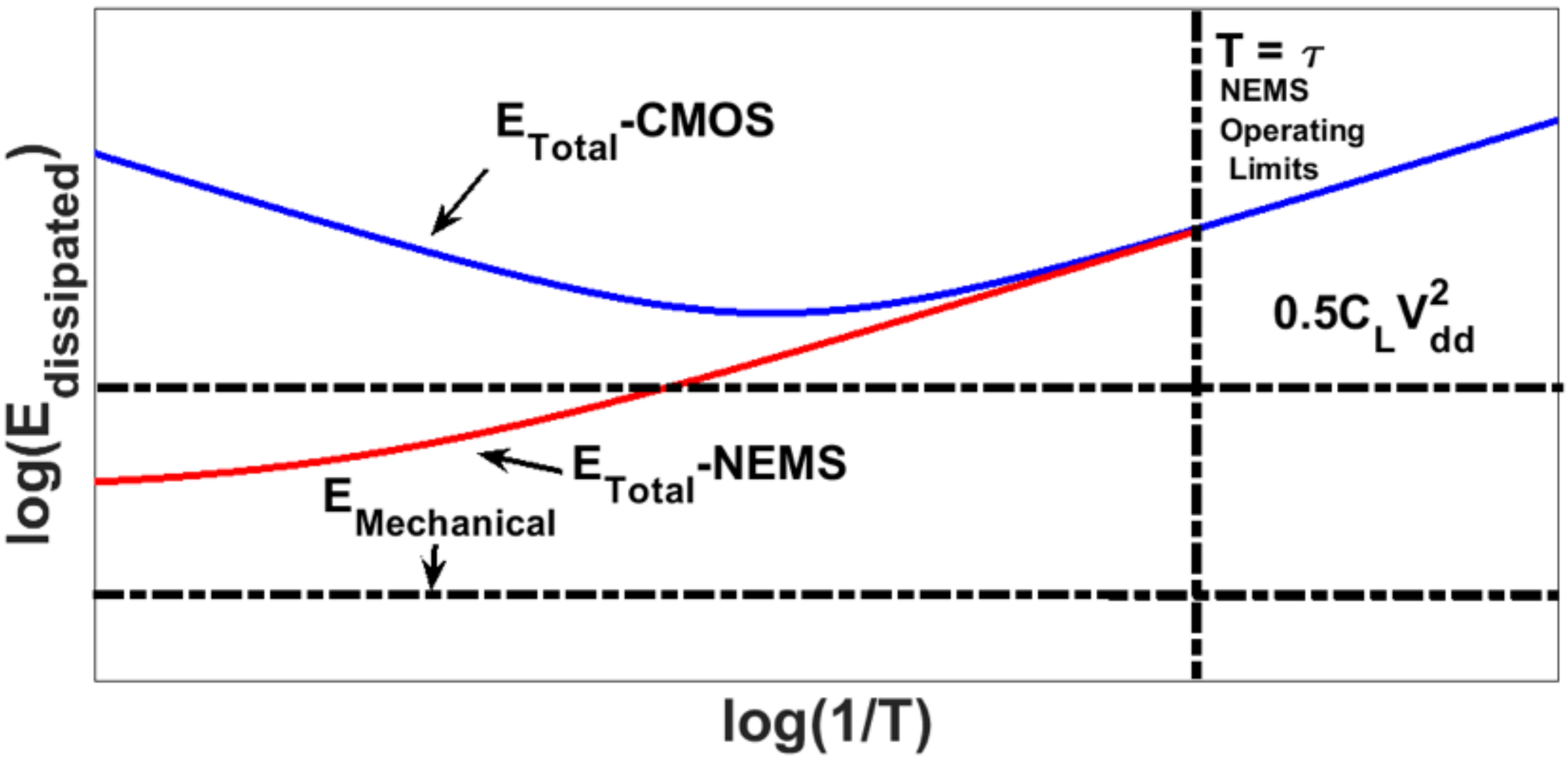
NEMS Adiabatic Logic



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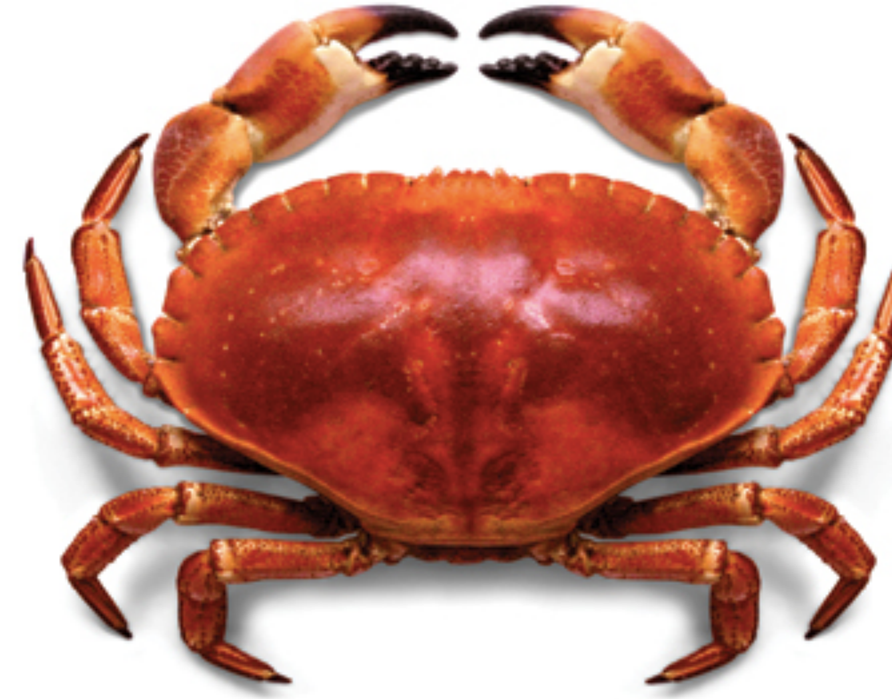


Unconventional computing

Robust Soldier Crab Ball Gate

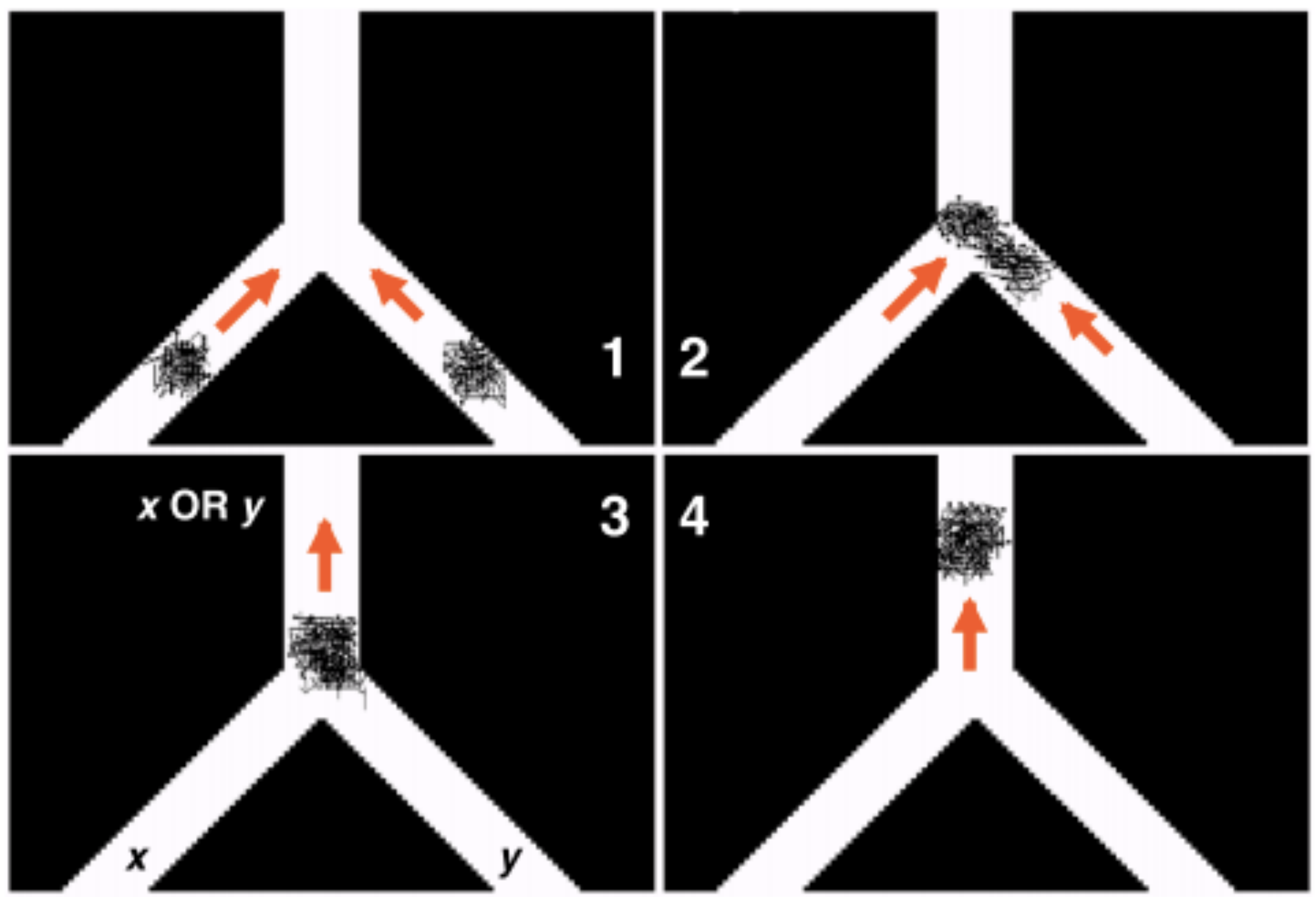
Yukio-Pegio Gunji
Yuta Nishiyama
Department of Earth and Planetary Sciences
Kobe University
Kobe 657-8501, Japan

Andrew Adamatzky

Unconventional Computing Centre
University of the West of England
Bristol, United Kingdom

Soldier crabs *Mictyris guinotae* exhibit pronounced swarming behavior. Swarms of the crabs are tolerant of perturbations. In computer models and laboratory experiments we demonstrate that swarms of soldier crabs can implement logical gates when placed in a geometrically constrained environment.

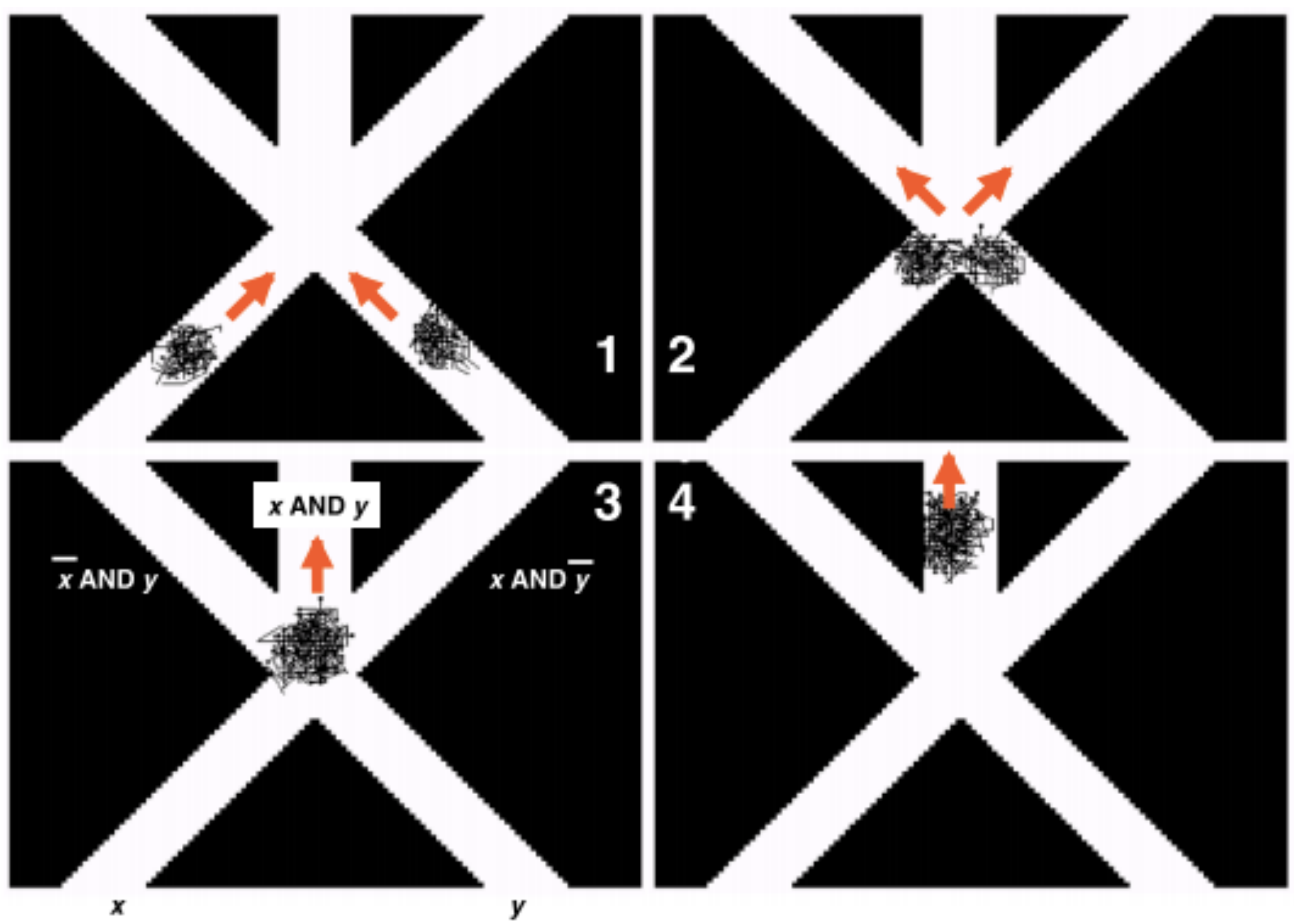
Robust Soldier Crab Ball Gate



OR gate

Robust Soldier Crab Ball Gate - Yukio-Pegio Gunji, Yuta Nishiyama, Andrew Adamatzky

Robust Soldier Crab Ball Gate



AND gate

Robust Soldier Crab Ball Gate - Yukio-Pegio Gunji, Yuta Nishiyama, Andrew Adamatzky

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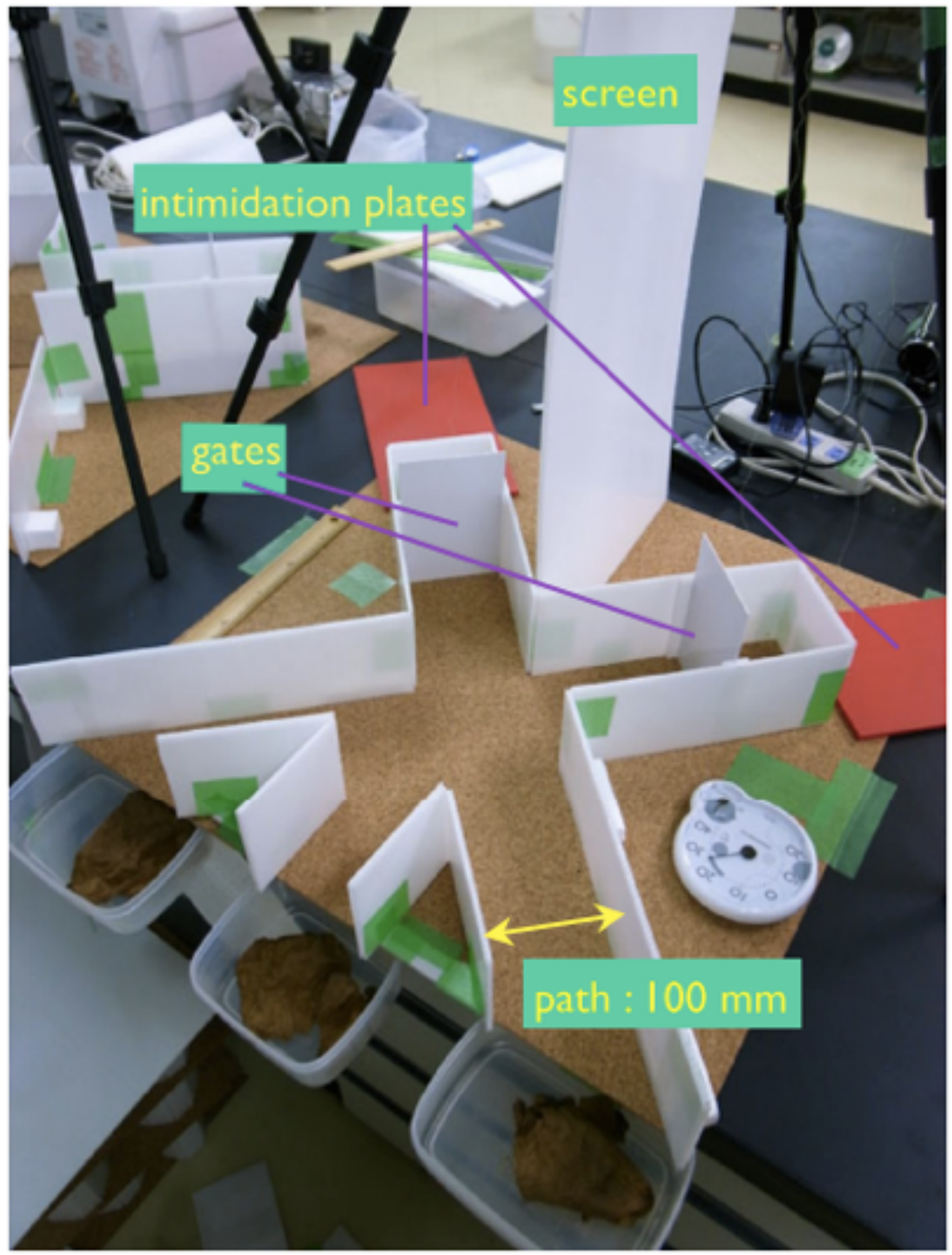

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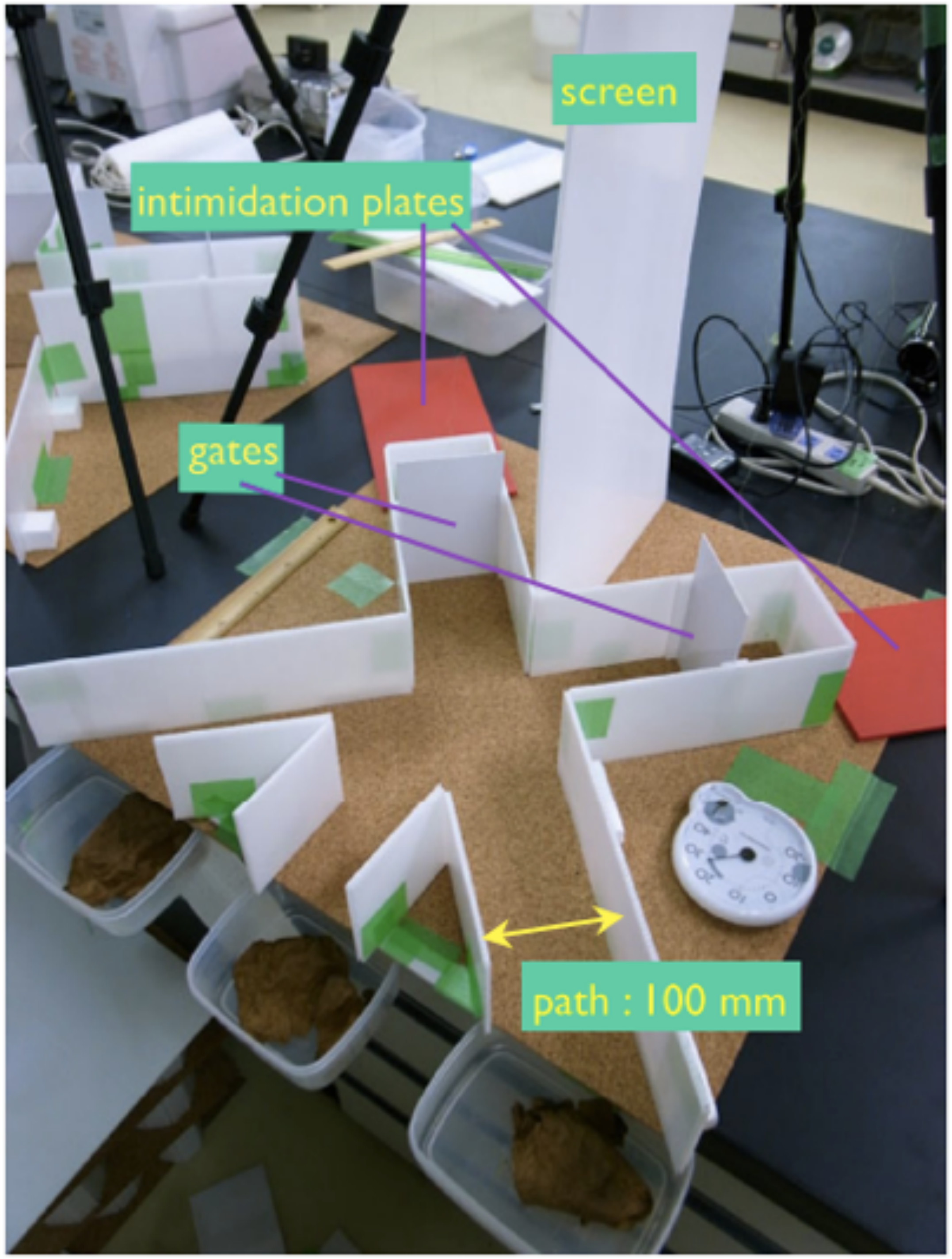
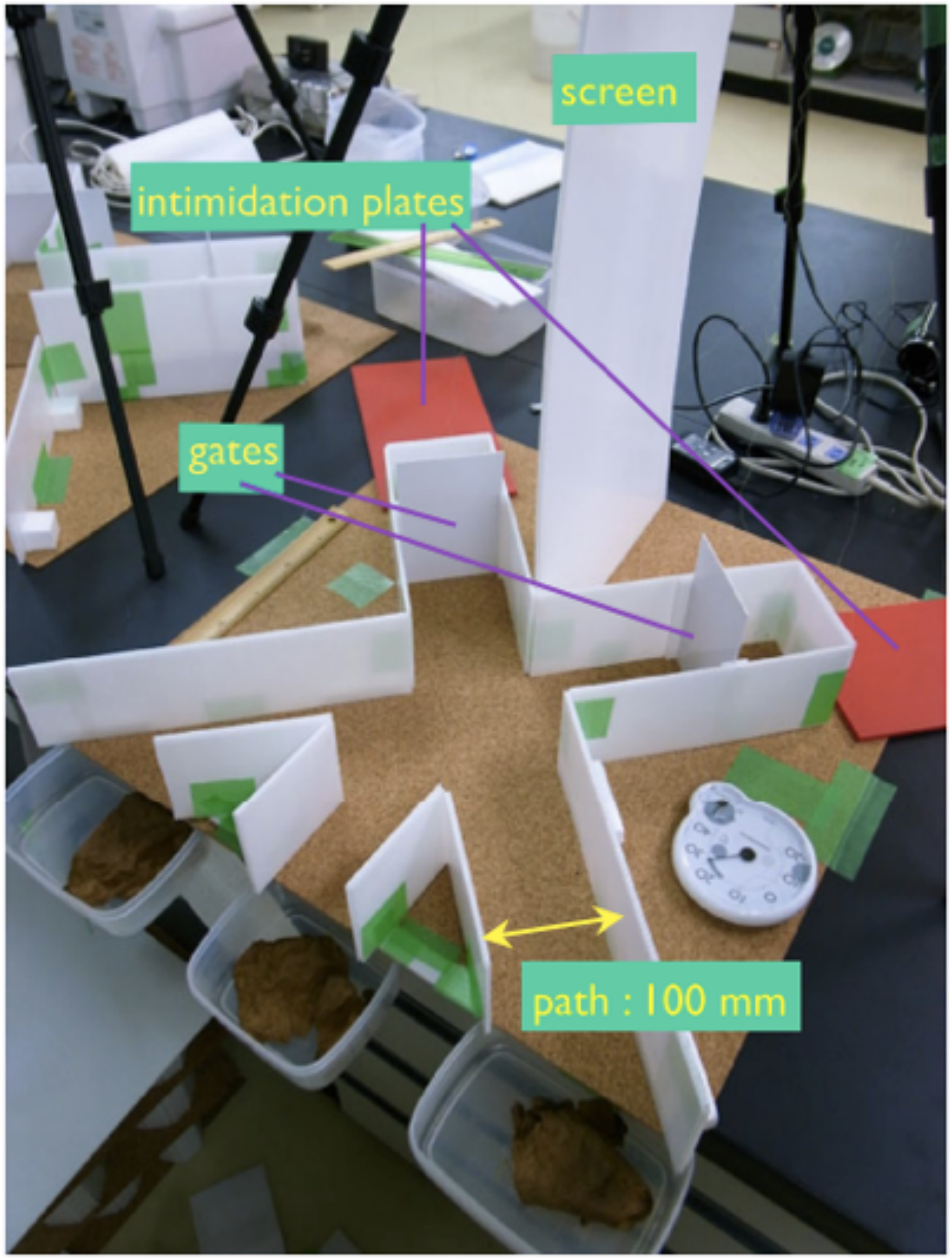


Robust Soldier Crab Ball Gate

- How much energy?



Robust Soldier Crab Ball Gate

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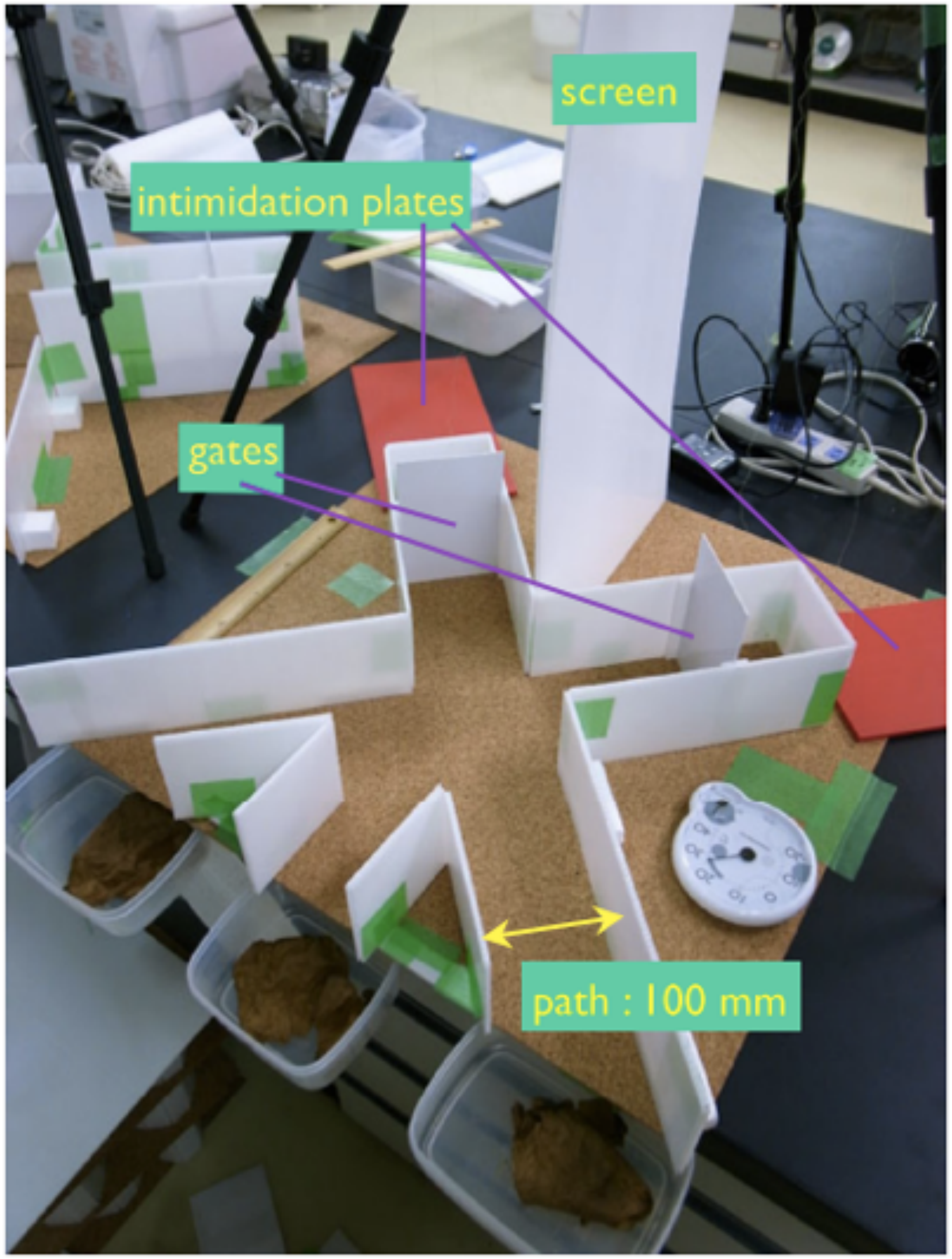
- Crabs usually eat algae. Crabs are omnivorous, meaning that they will eat both plants and other animals for sustenance.



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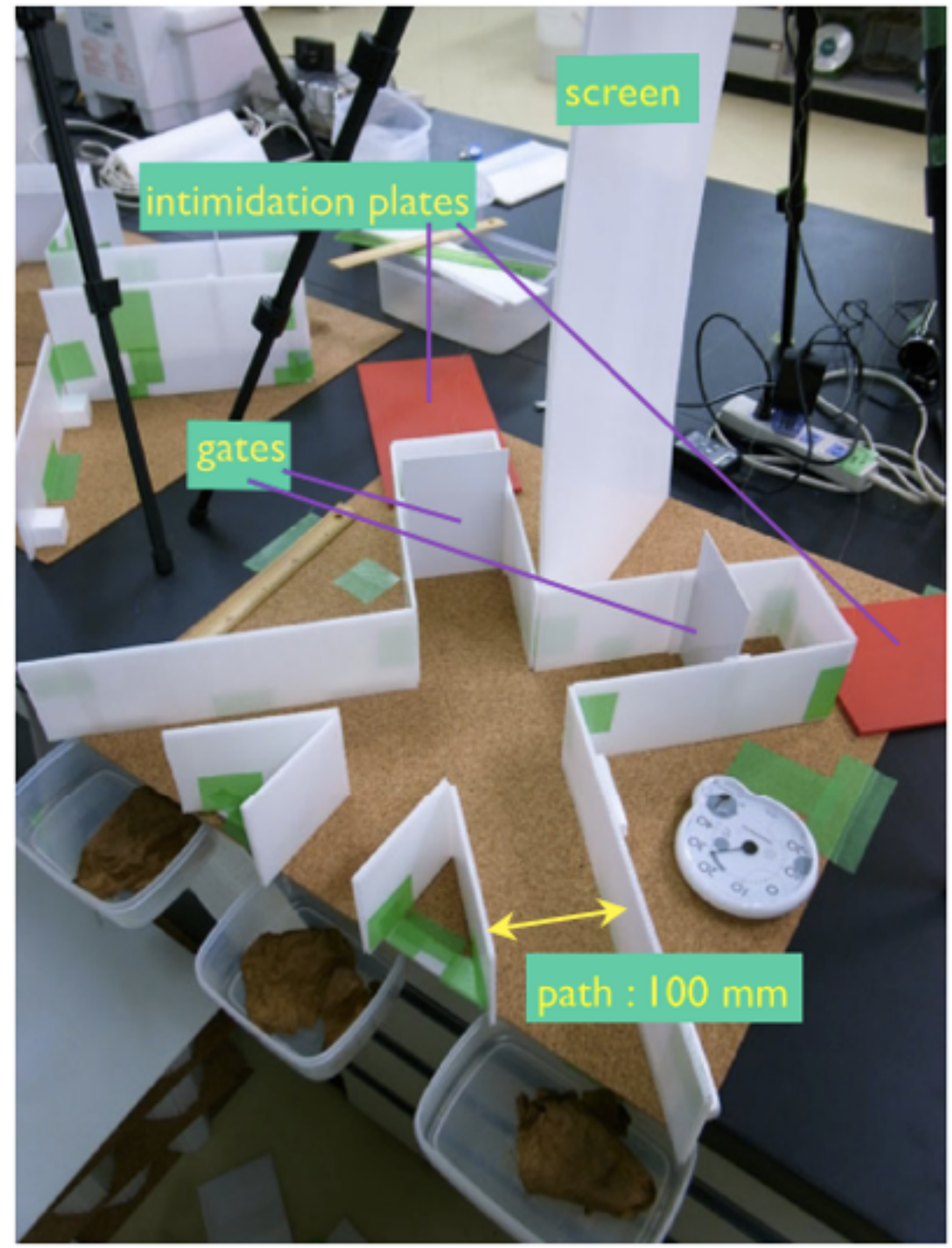

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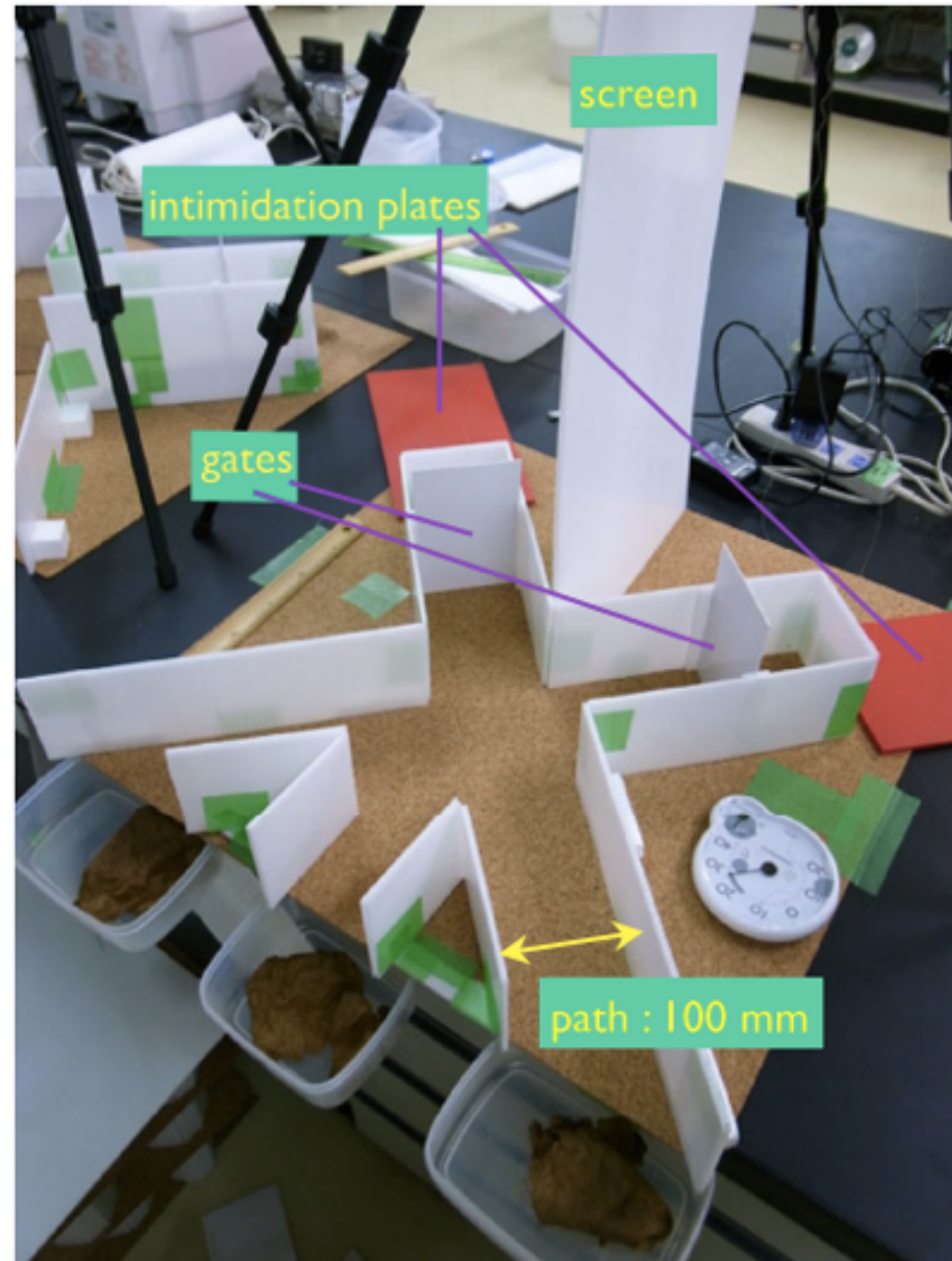

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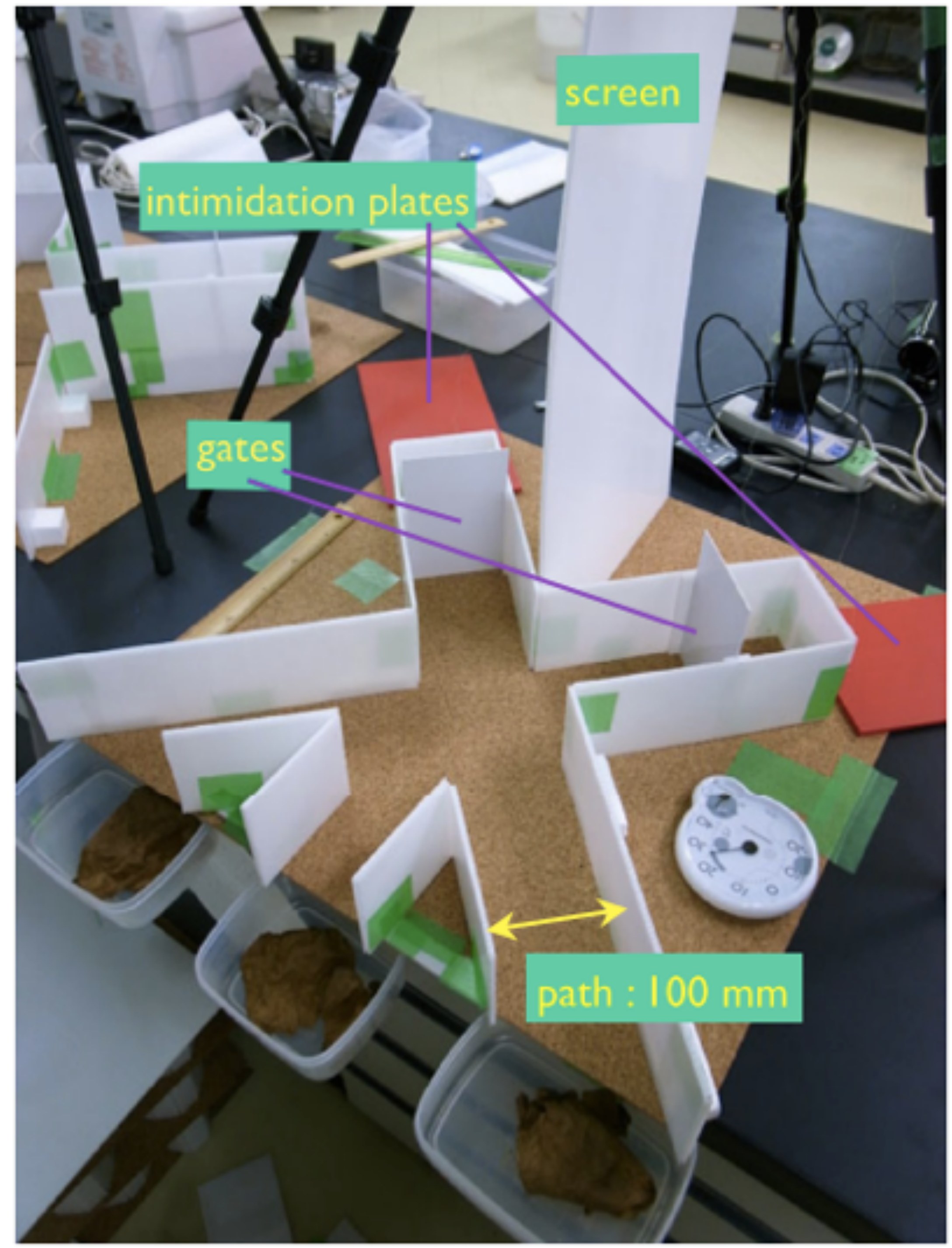

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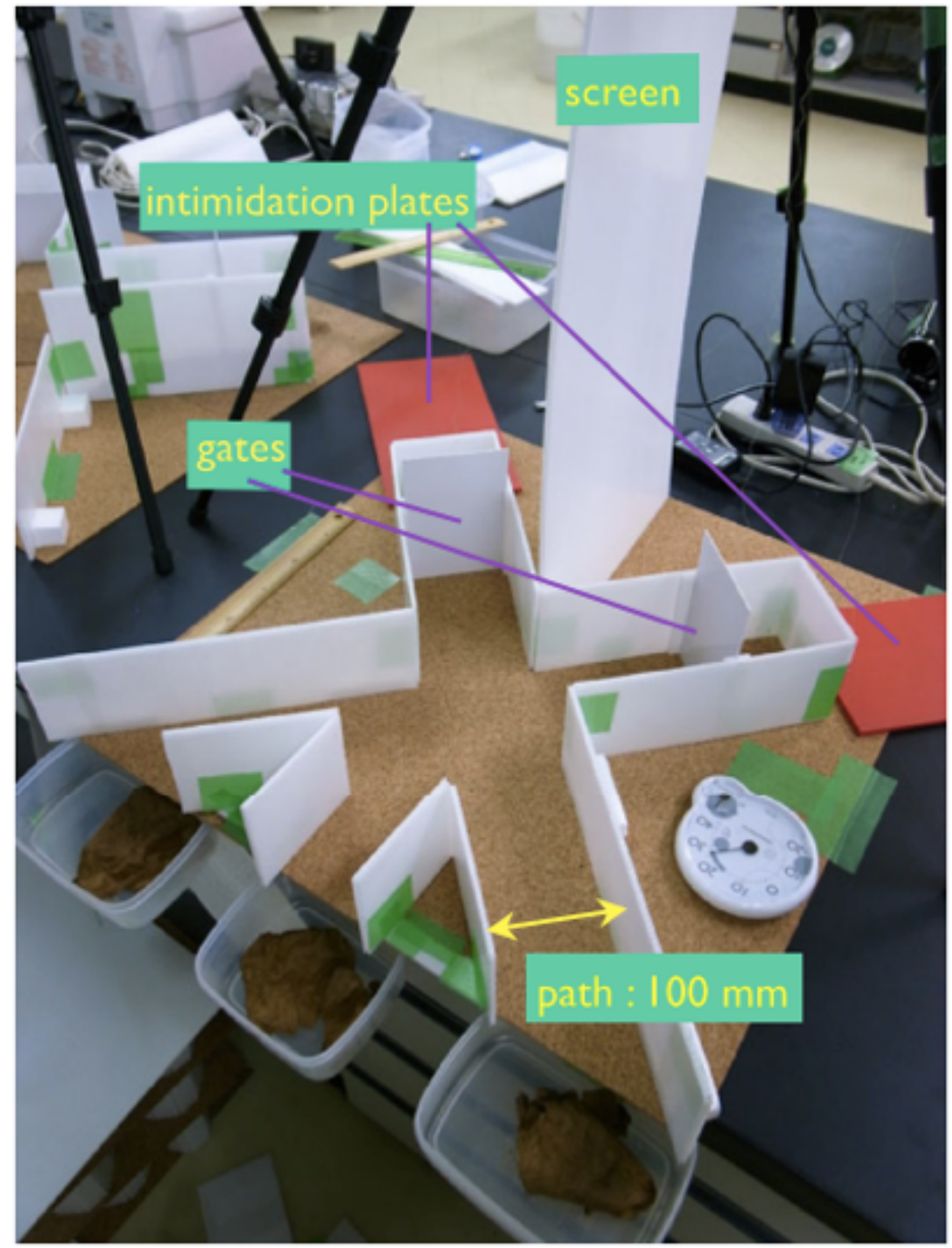
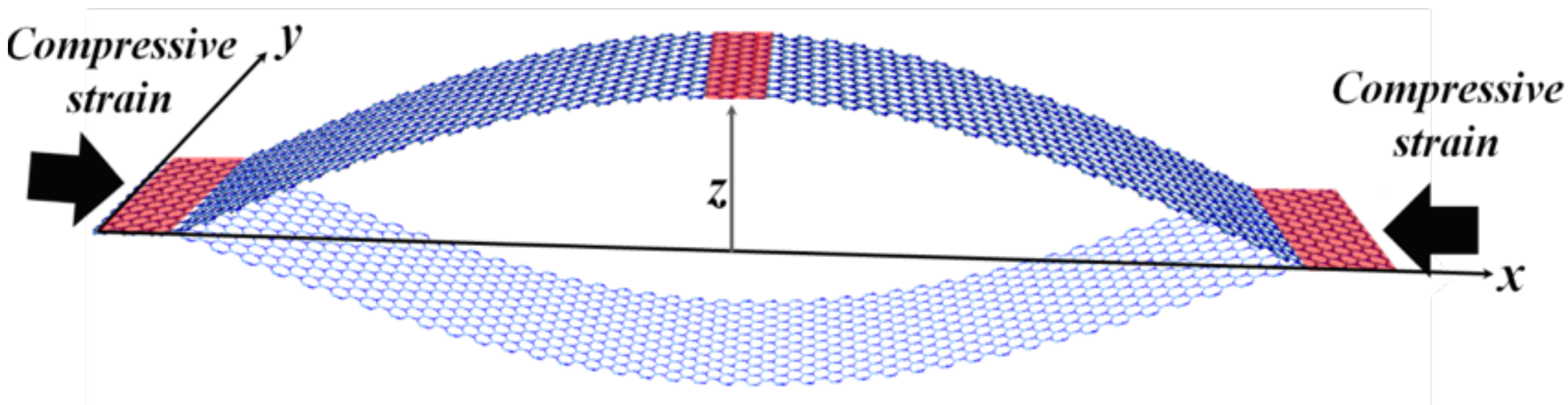
- 146440J of energy for daily operating a crab logic gate or 1.7W of power



What about the memory?

NEMS system



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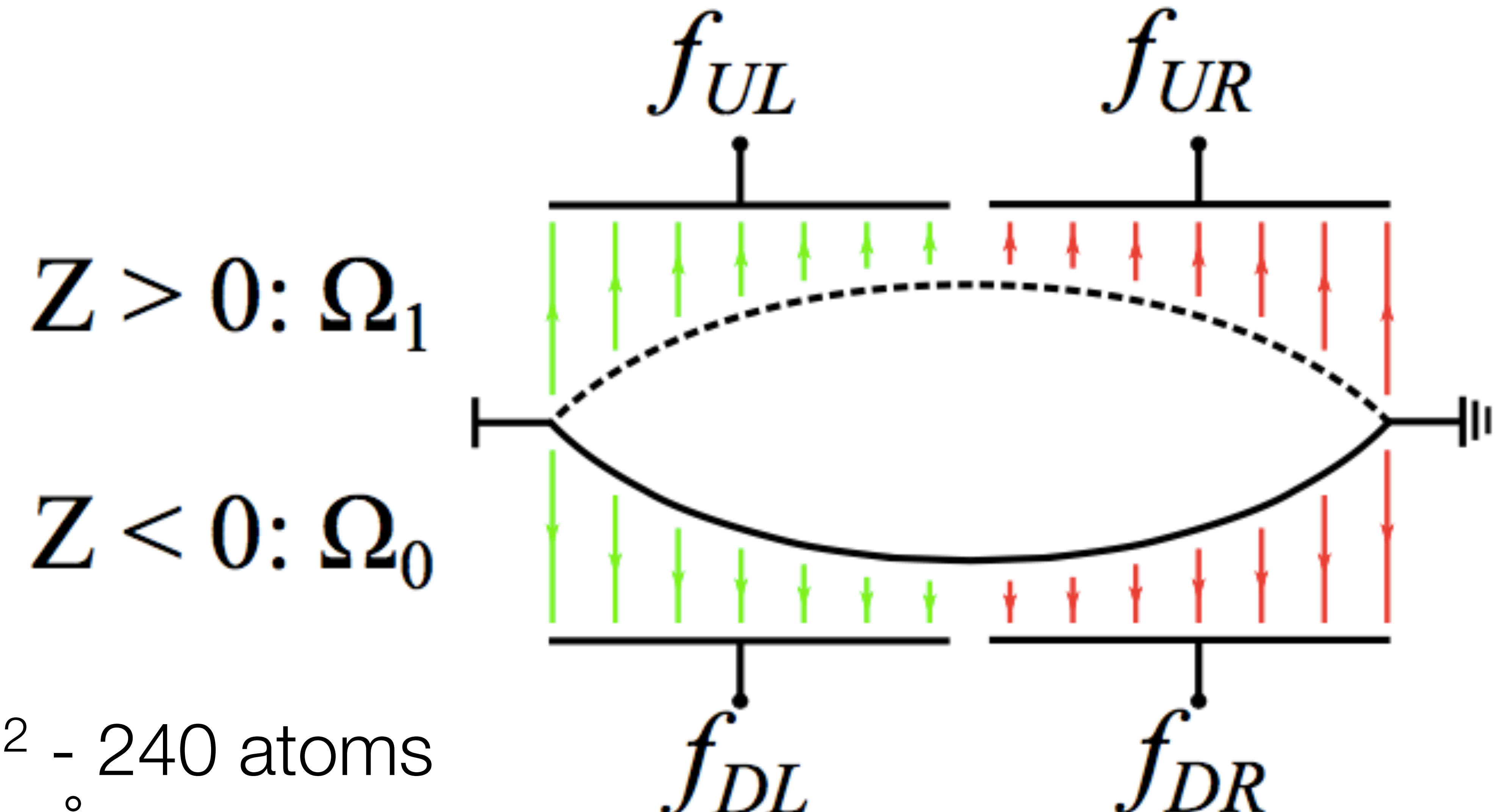

6x1 nm^2 - 240 atoms
a = 2.42 Å
Y = 0.85 TPa
T = 10 K

Heat production evaluation

$$H(\mathbf{P}, \mathbf{R}, t) = H_{kin}(\mathbf{P}) + H_{int}(\mathbf{R}) + H_{ext}(\mathbf{R}, t)$$

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$$H_{ext}(\mathbf{R}, t) = \sum_{i=1}^{n} \Bigg[\theta\left(x_i - \tfrac{l}{2}\right) \left(\frac{f_{UL}(t)}{(g - z_i)} - \frac{f_{DL}(t)}{(g + z_i)} \right) + \\ + \theta\left(\tfrac{l}{2} - x_i\right) \left(\frac{f_{UR}(t)}{(g - z_i)} - \frac{f_{DR}(t)}{(g + z_i)} \right) \Bigg]$$

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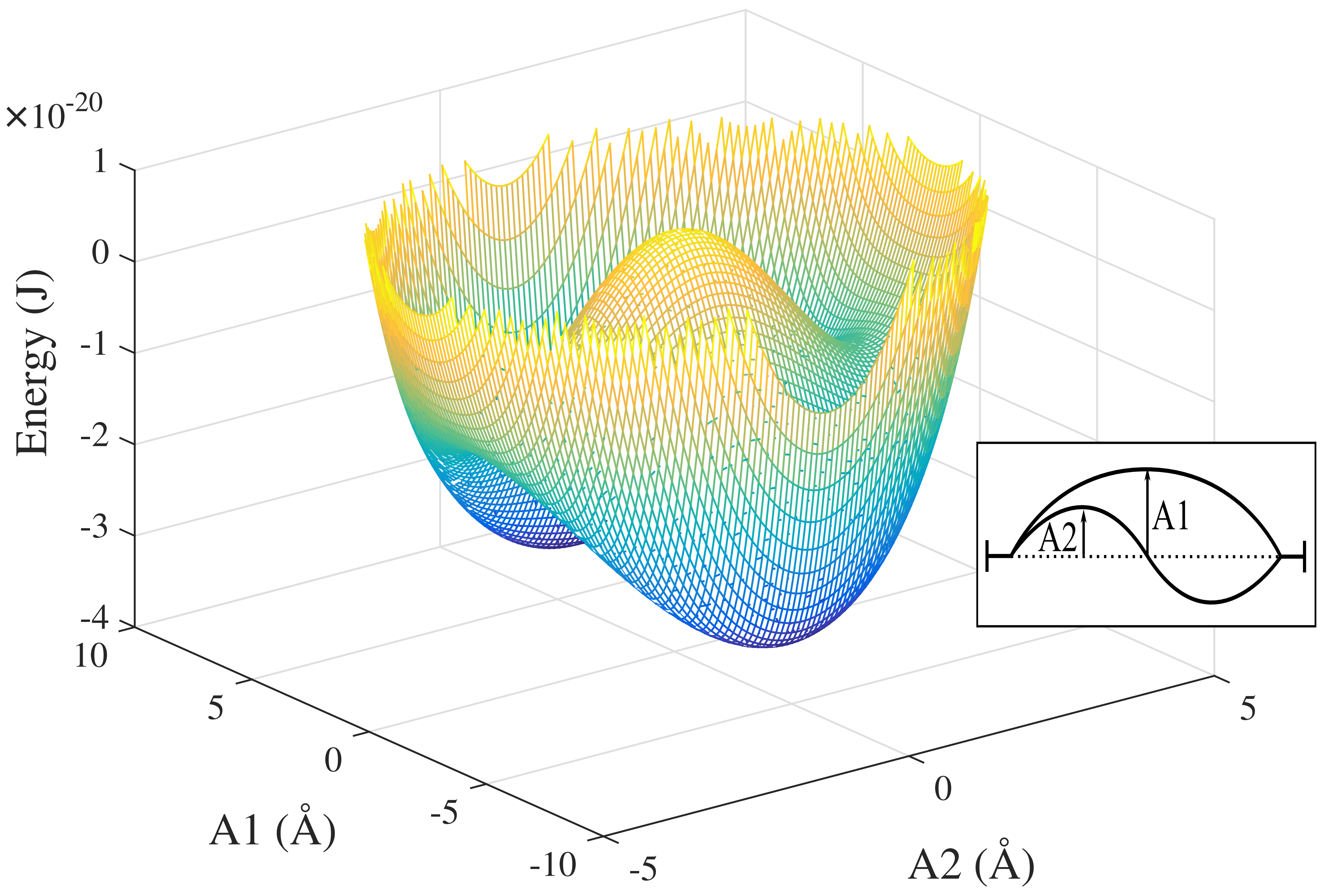
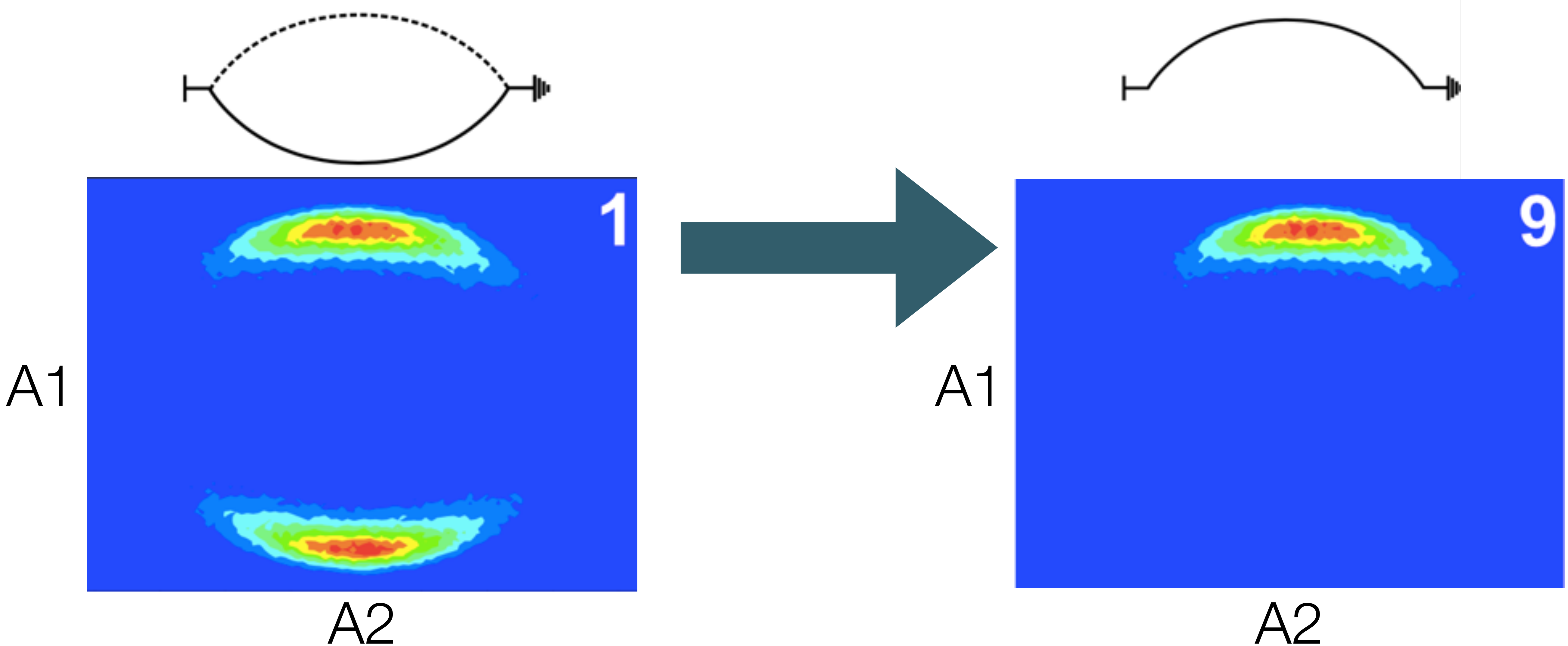
2-DOF potential landscape



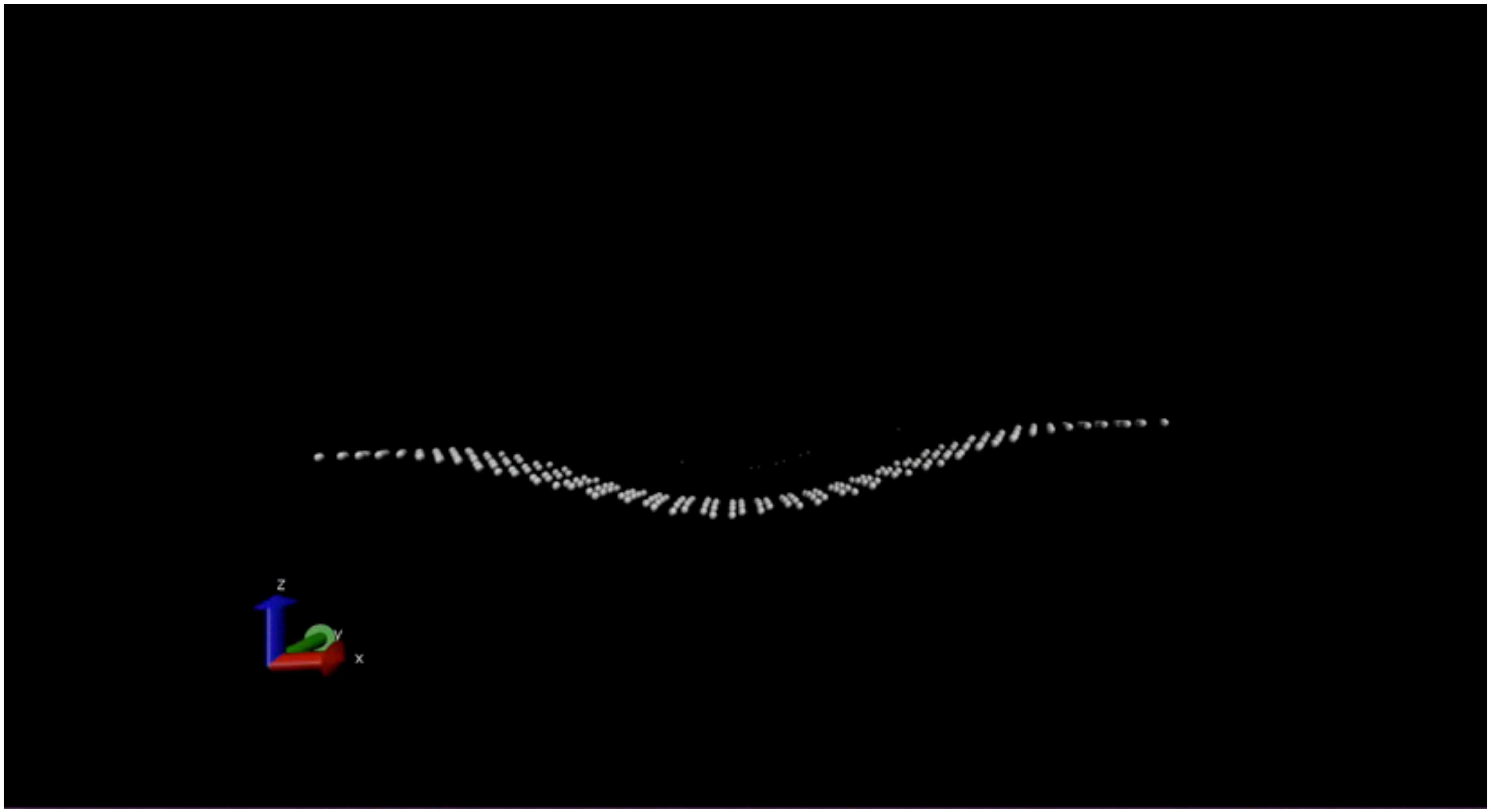
Reset protocol

- Objective: move the system from an unknown state to known state
- $\Delta S = k_B \log(2)$
- $Q_{min} = k_B T \log(2)$



Reset protocol

Quick and dirty: apply a positive force along Z on all atoms



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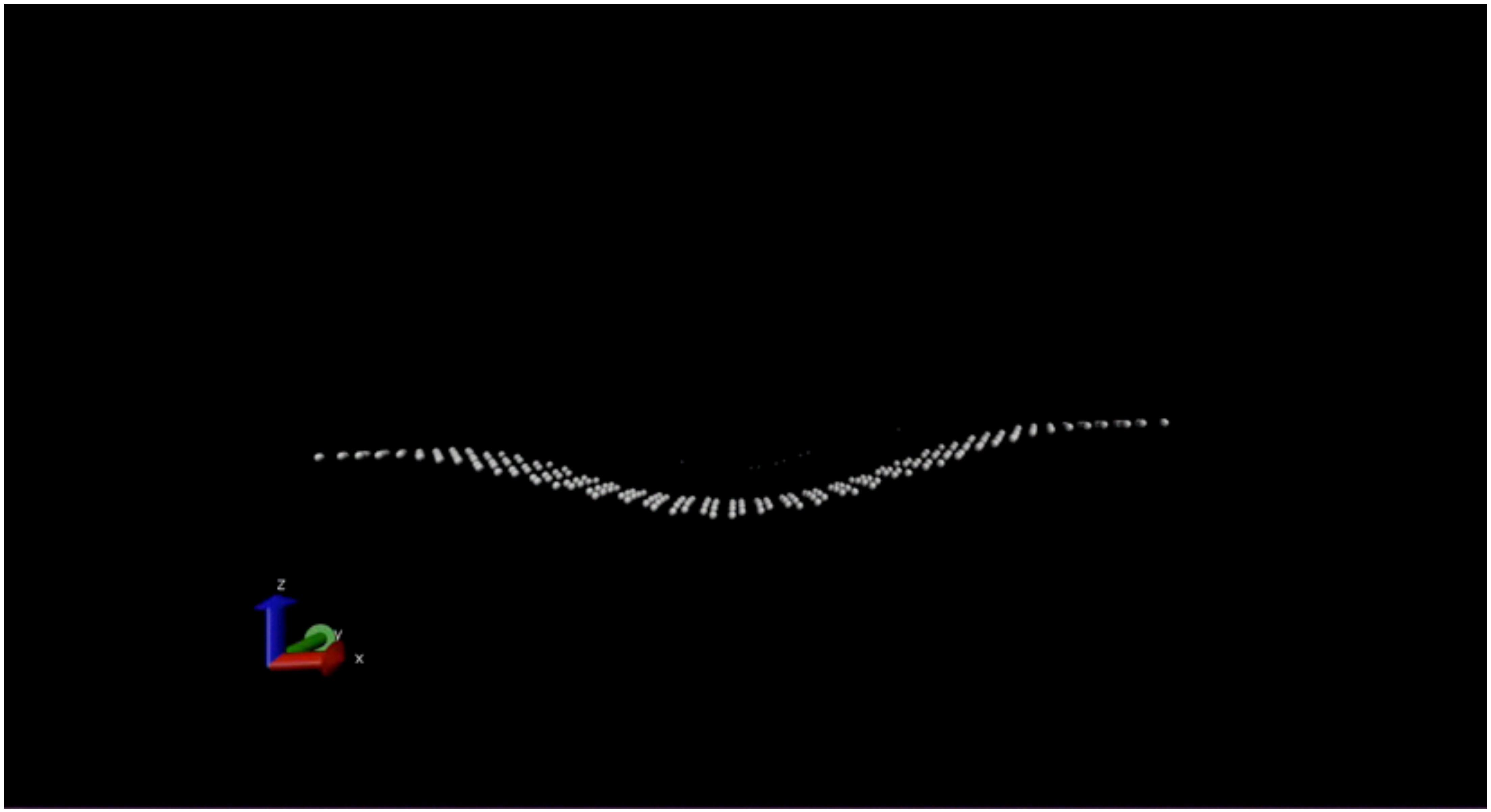

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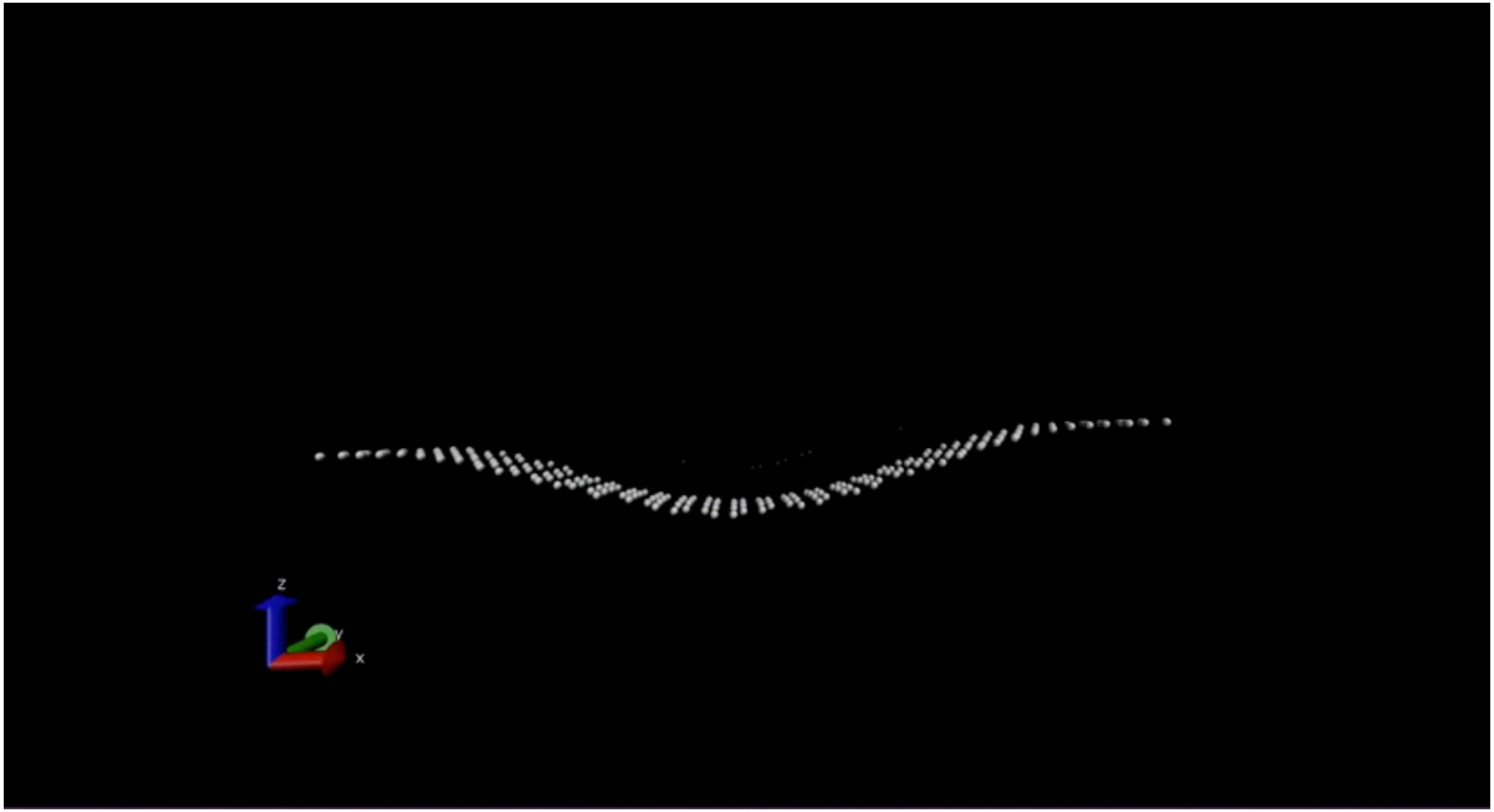

WRONG: it is not possible to control the velocity!

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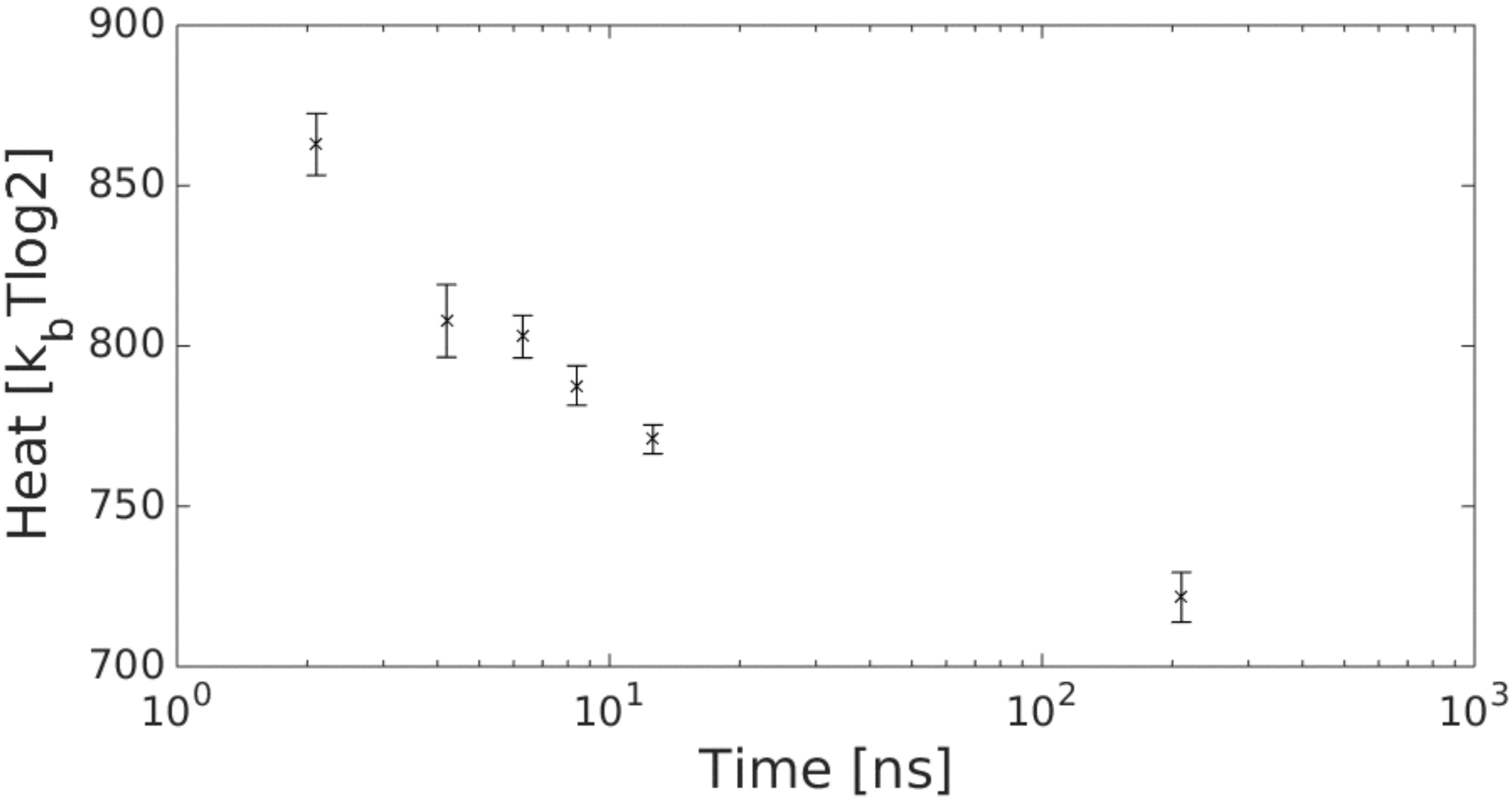
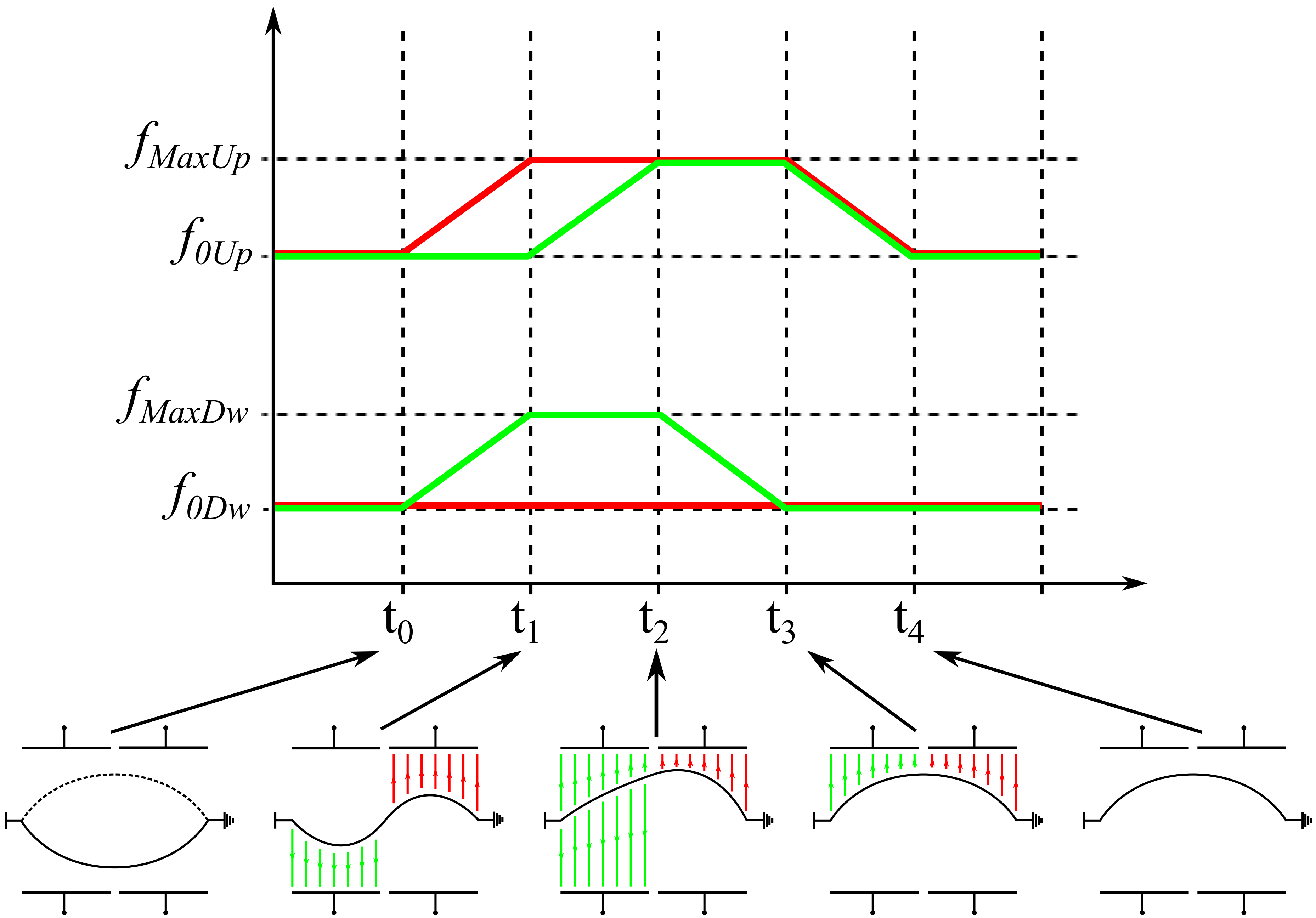


Reset protocol

Controlled way: apply a set of forces in to gently put the system in the desired configuration



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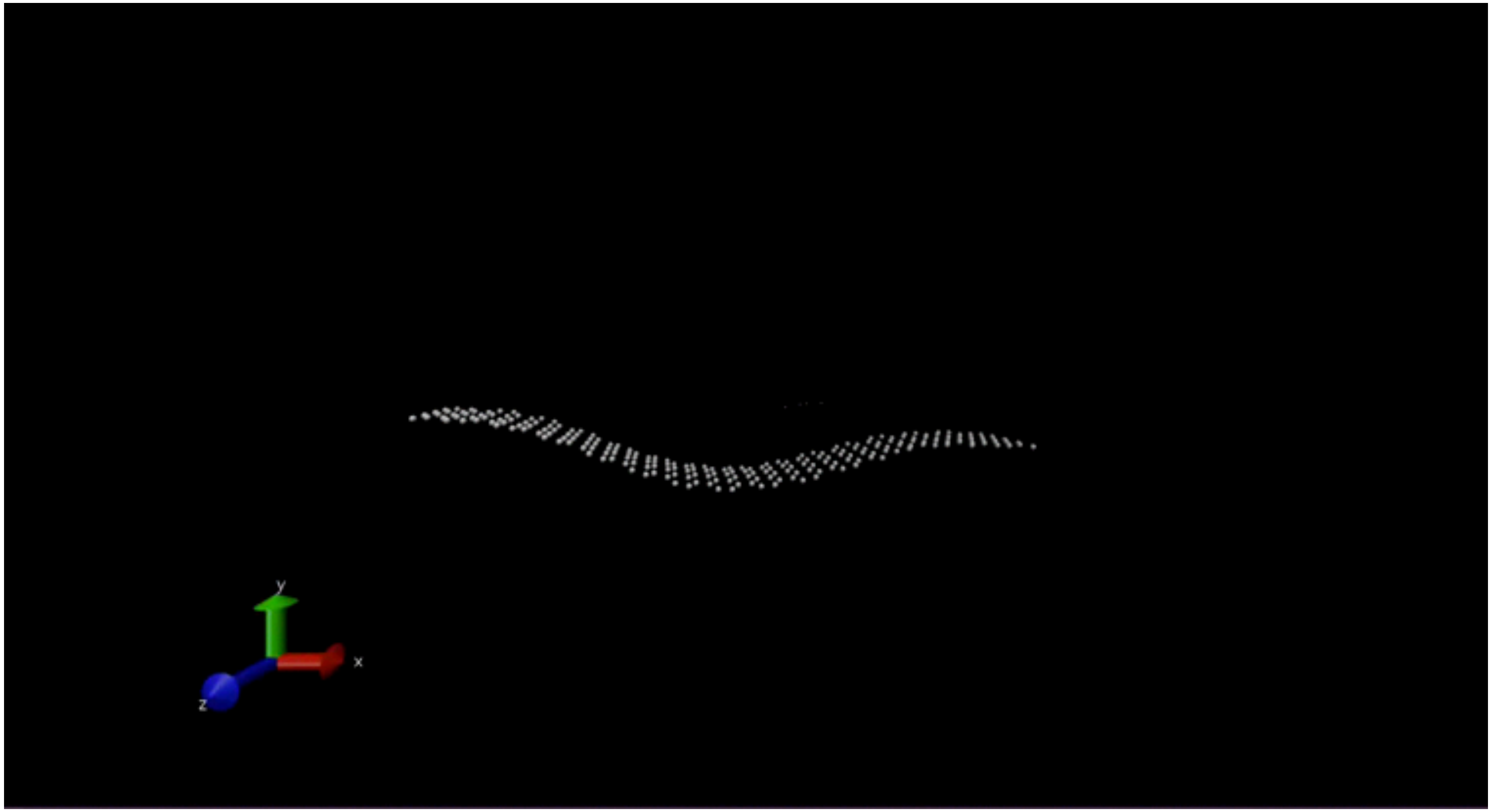

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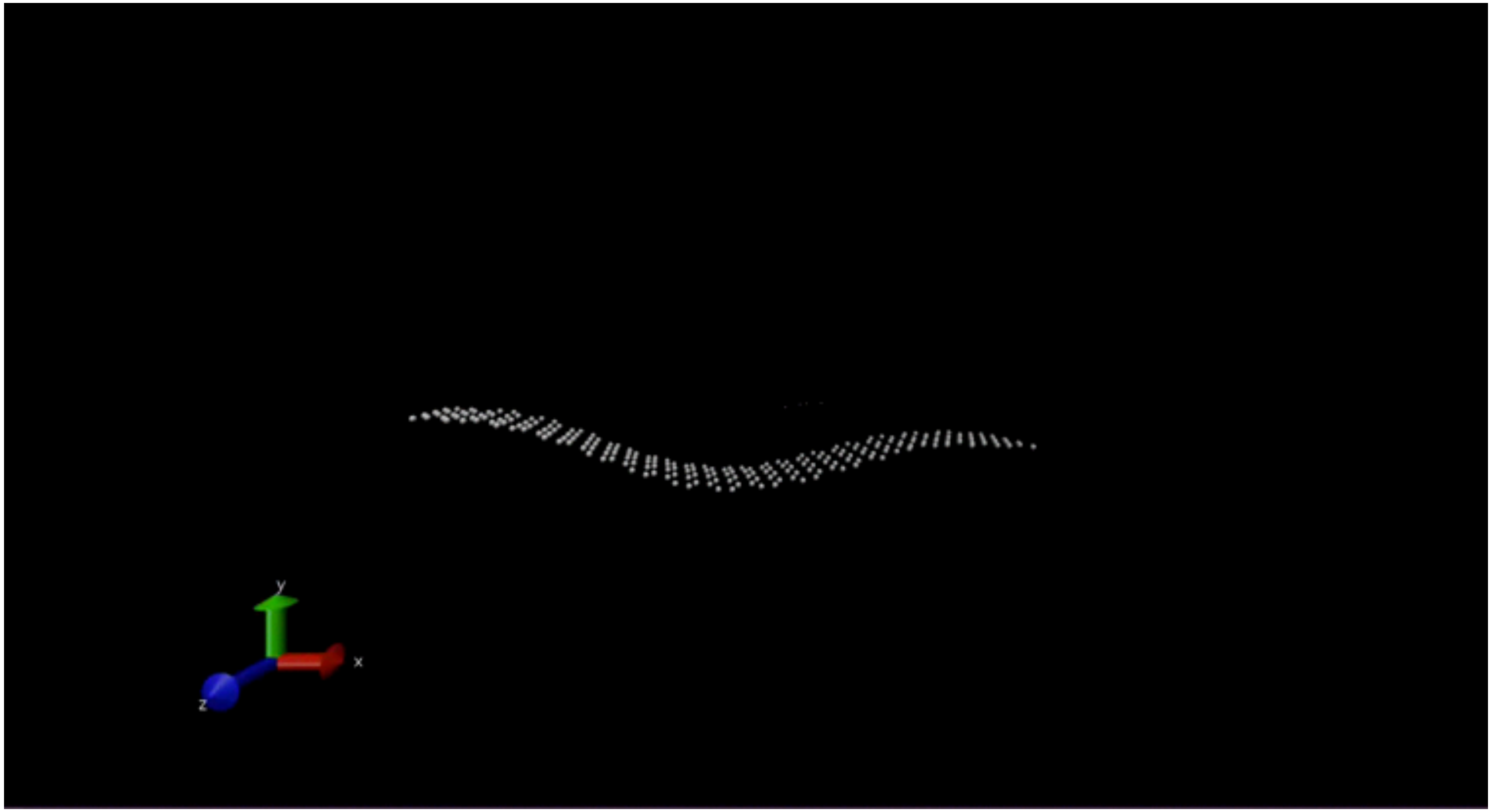

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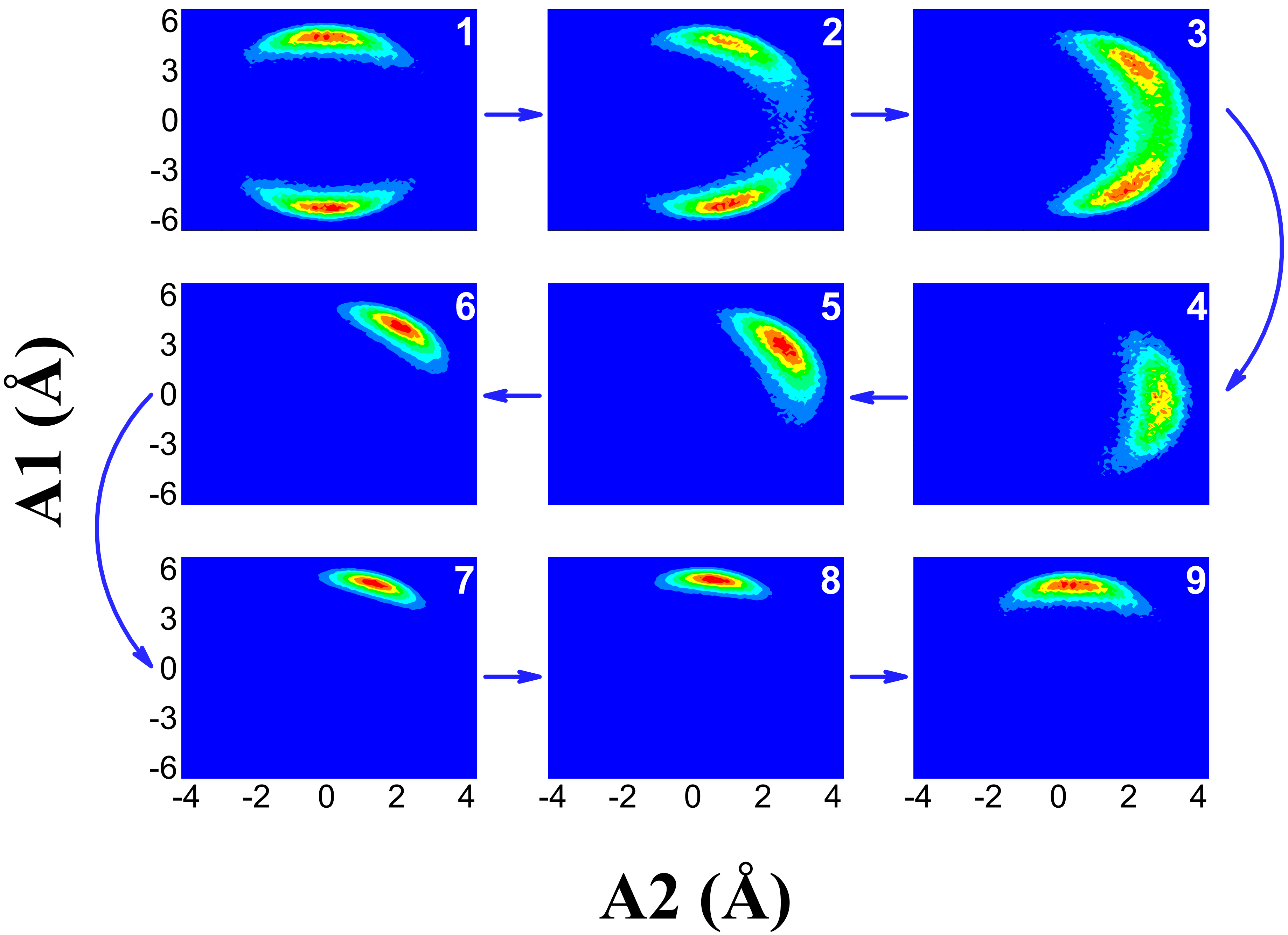

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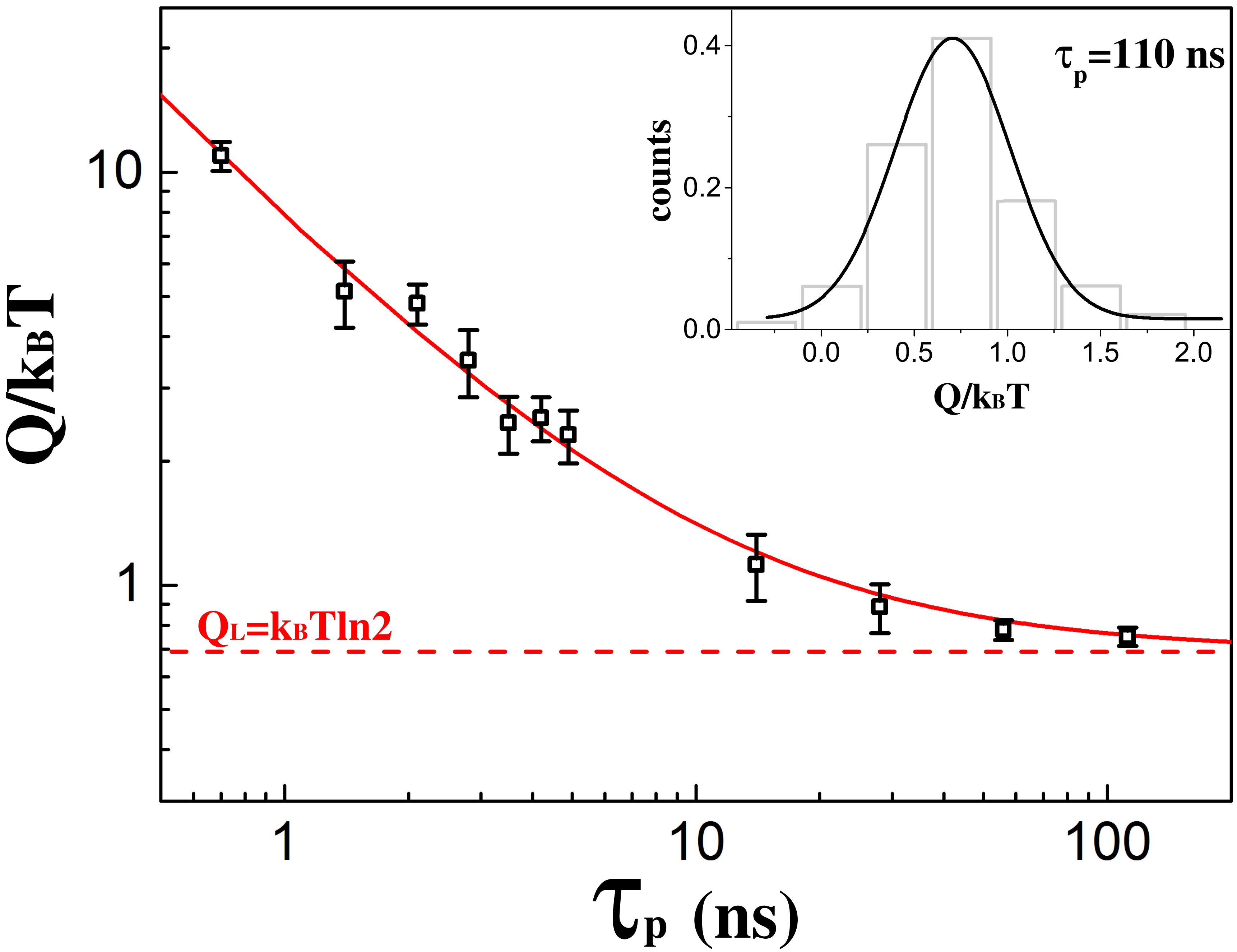
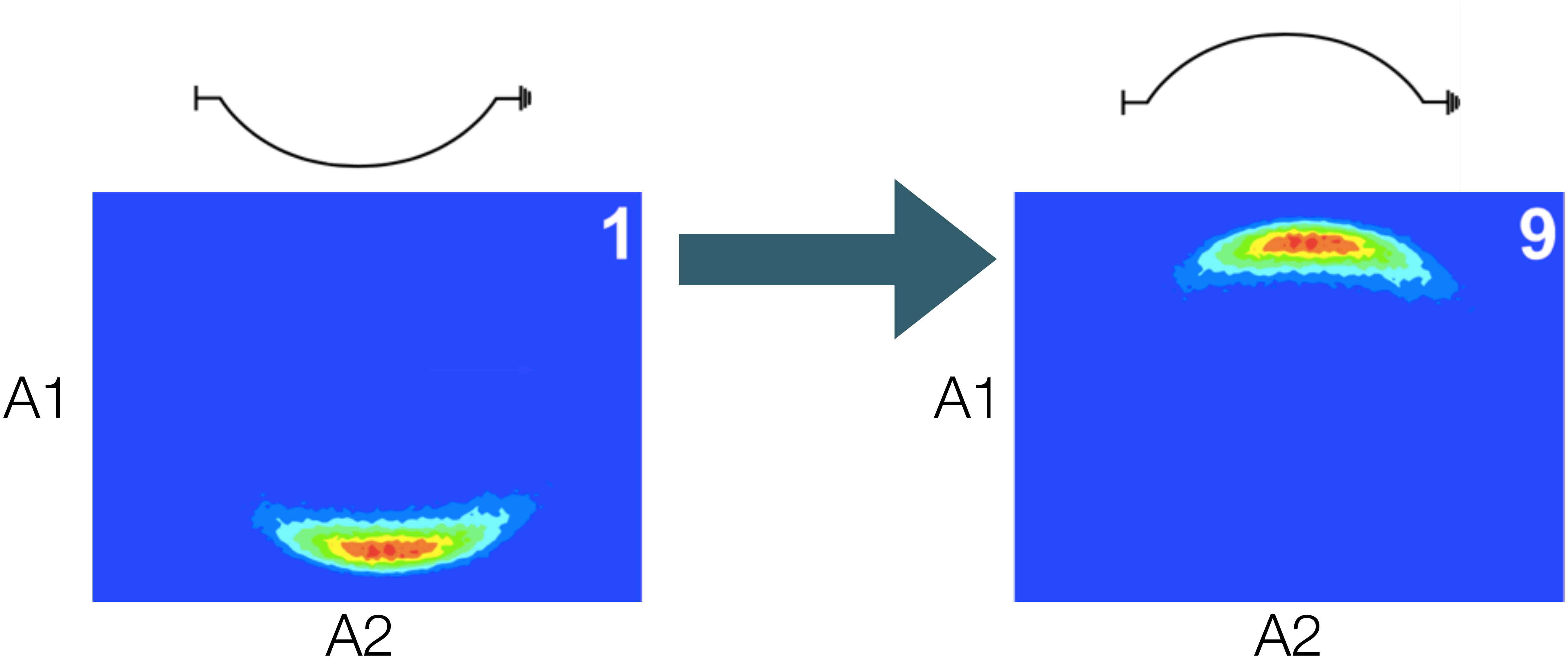


Switch protocol

- Objective: move the system from a known state to another known state
- $\Delta S = 0$
- $Q_{min} = 0$



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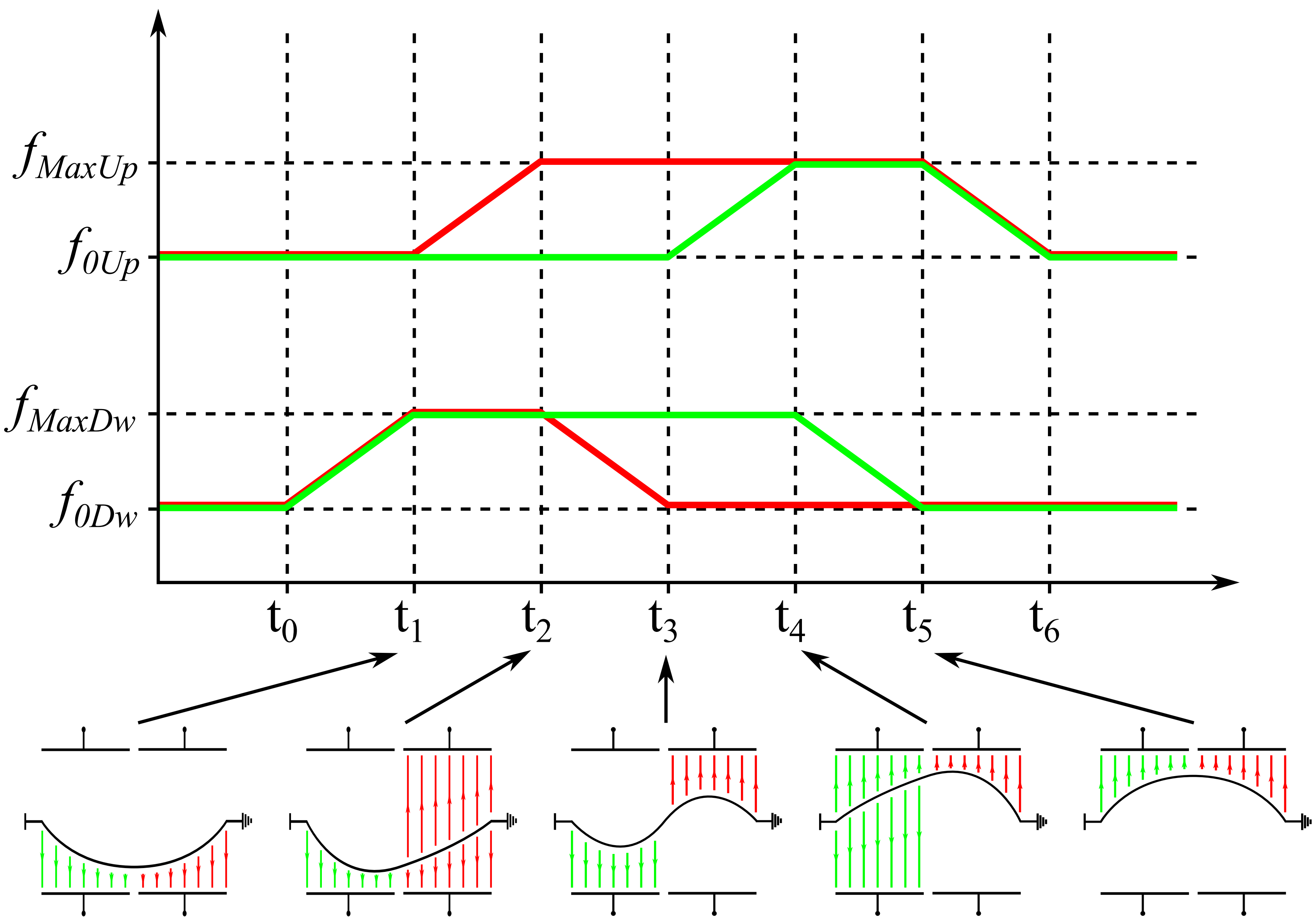

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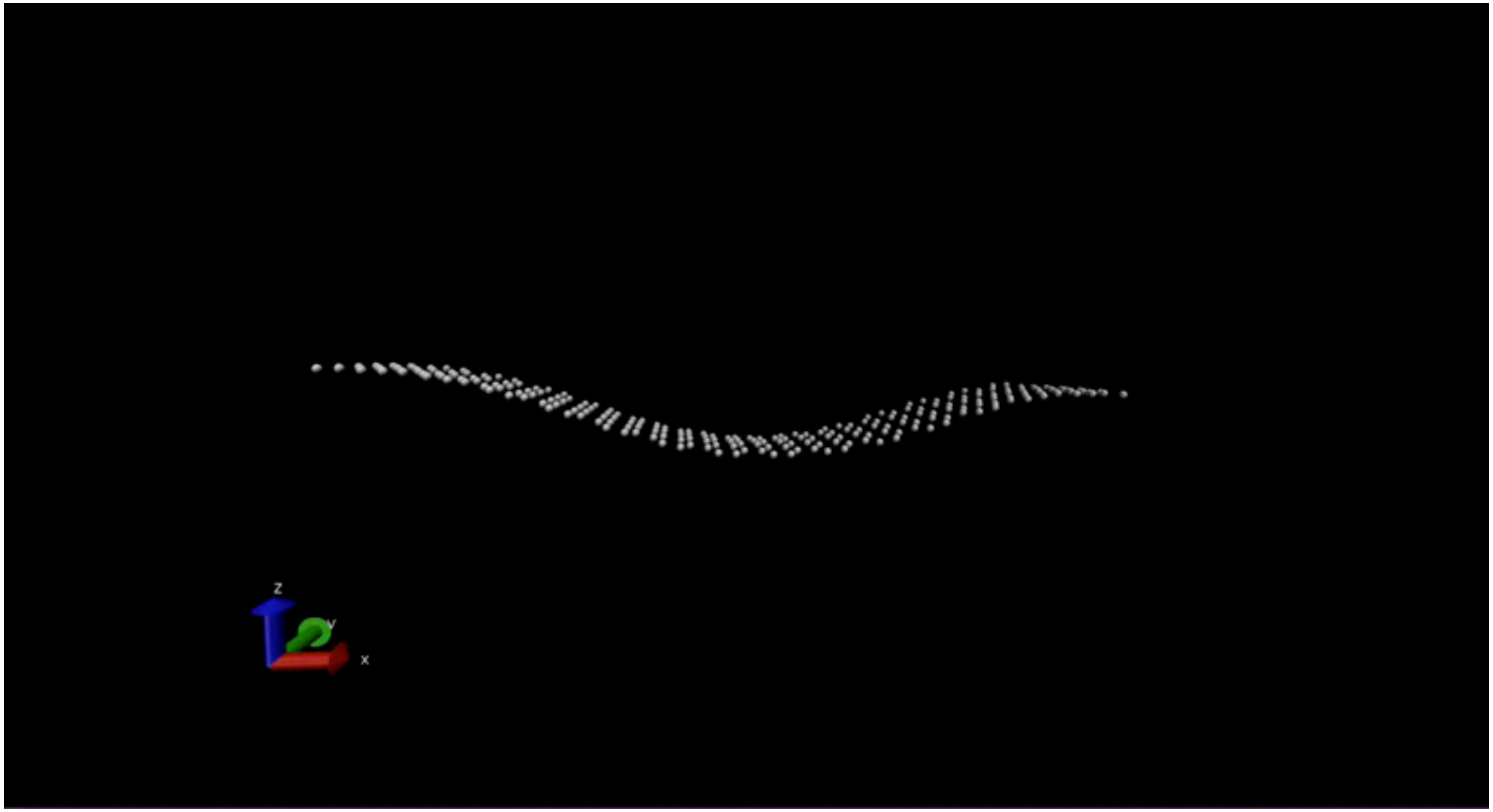

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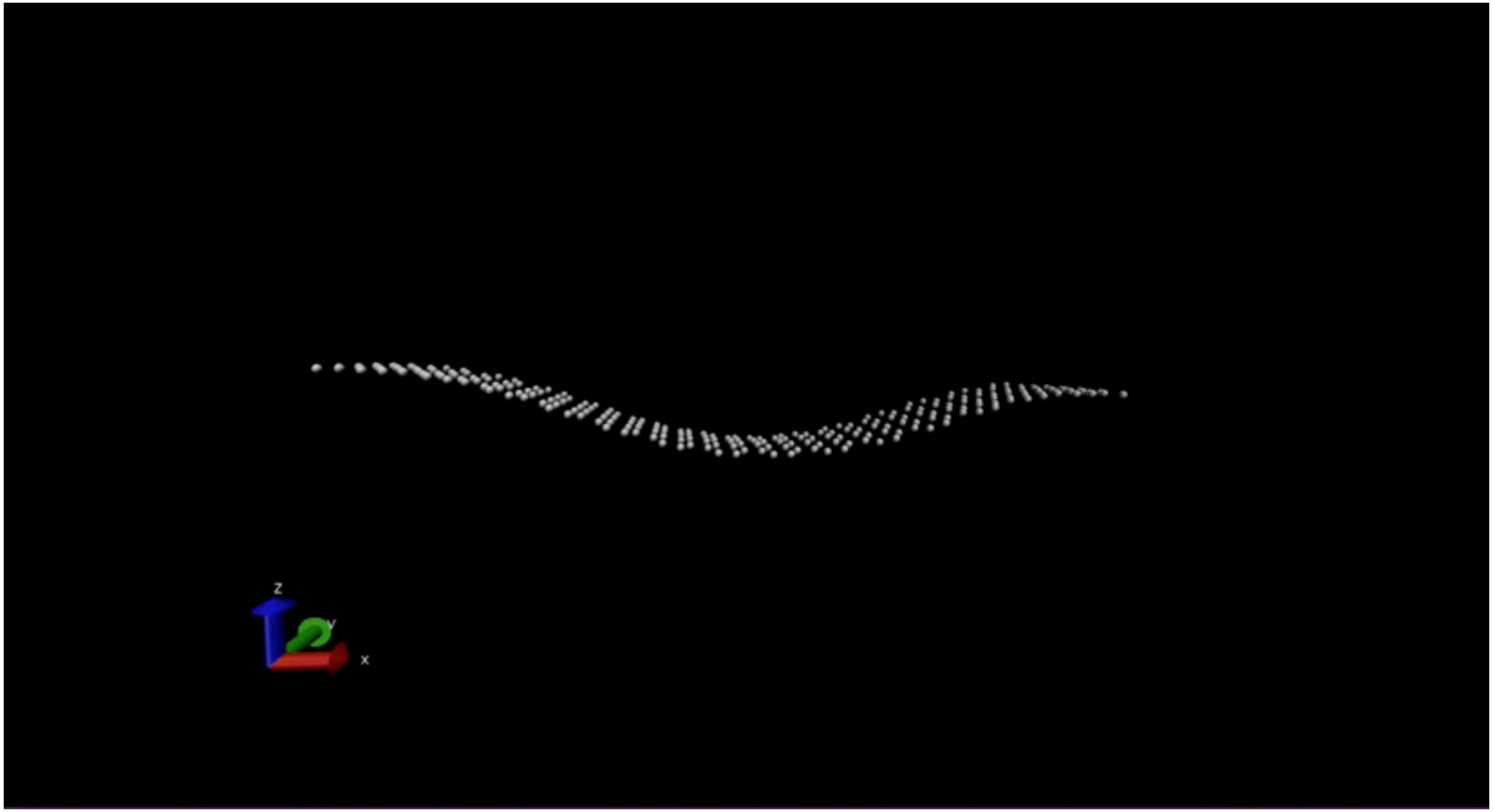

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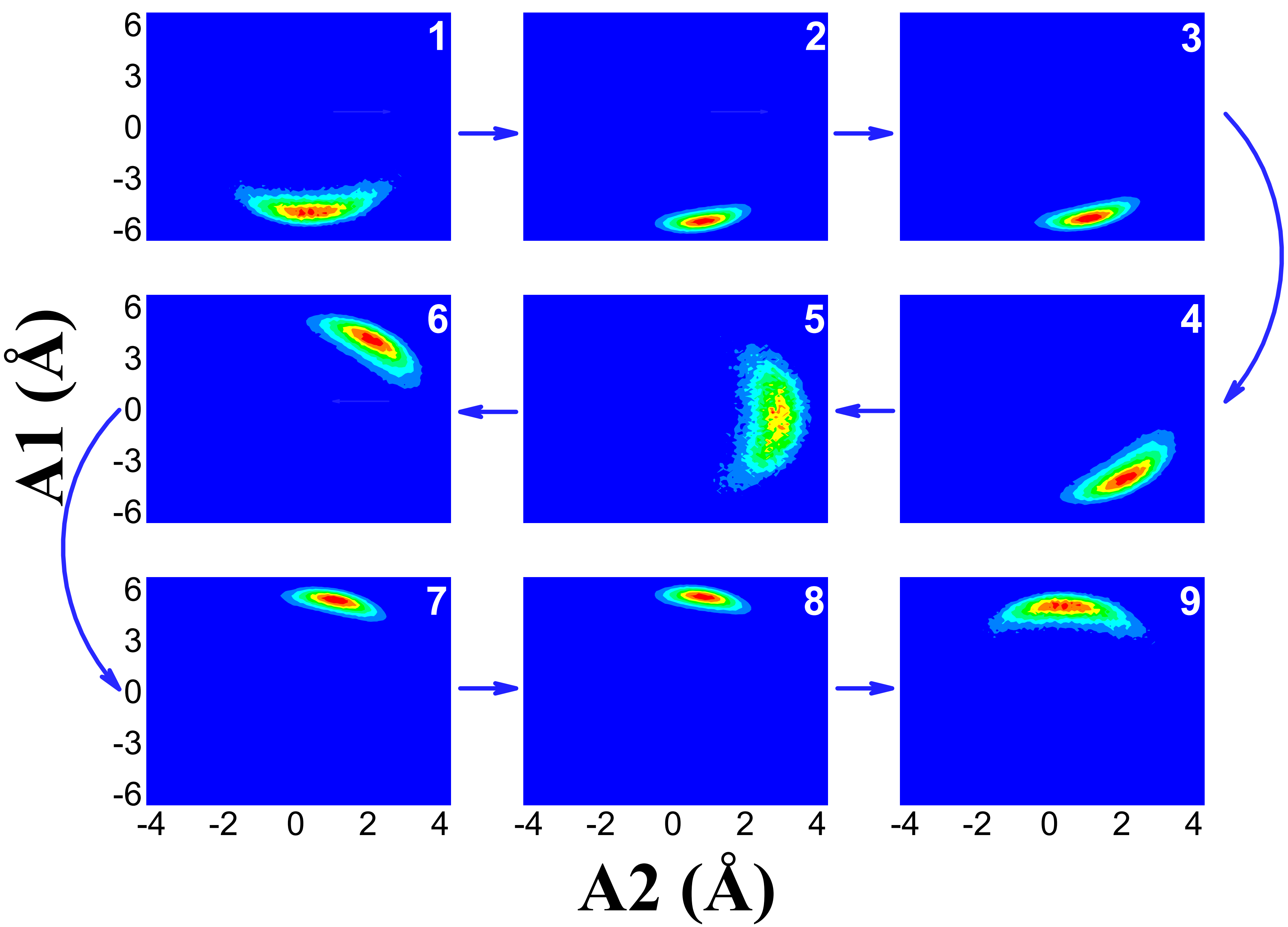

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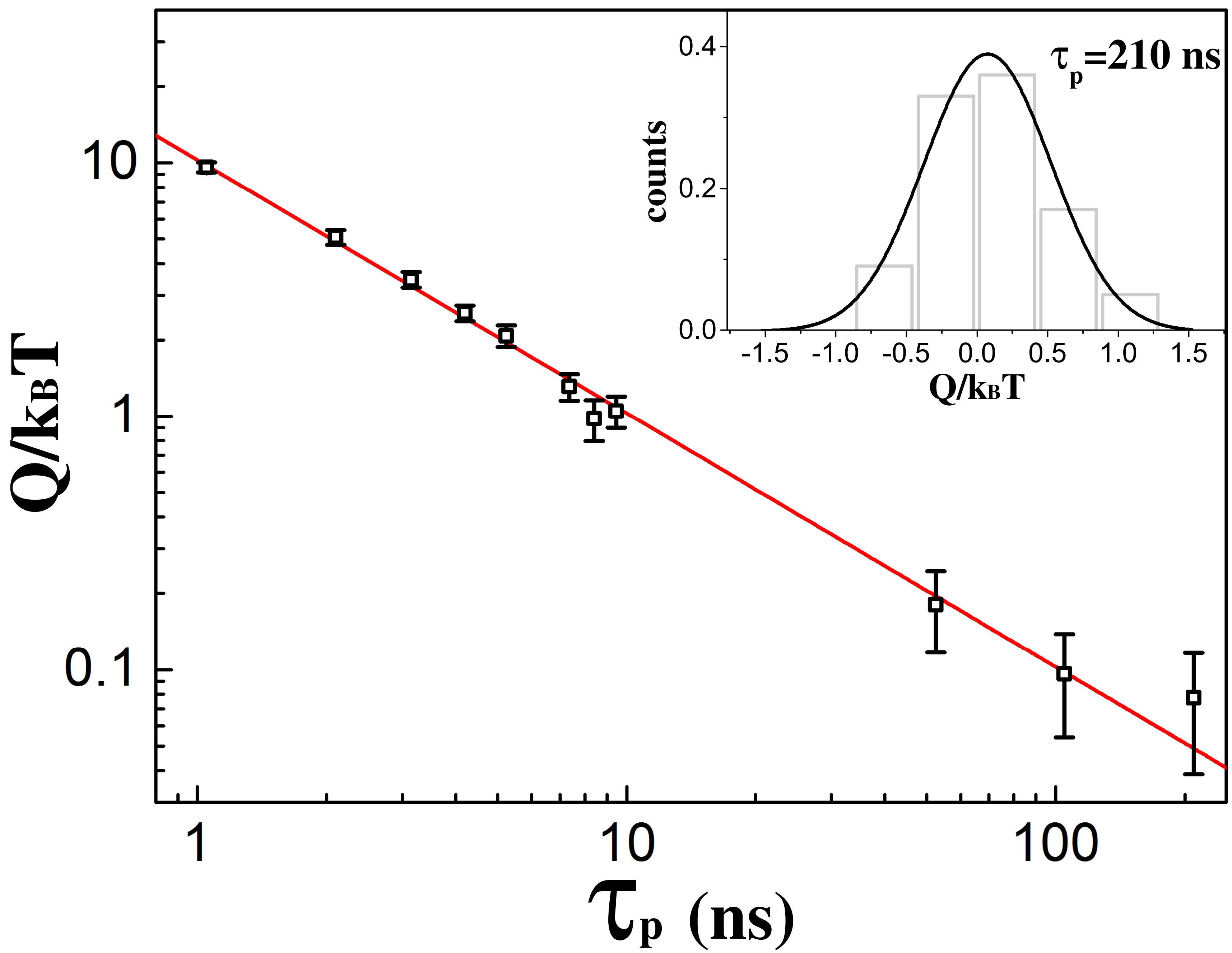
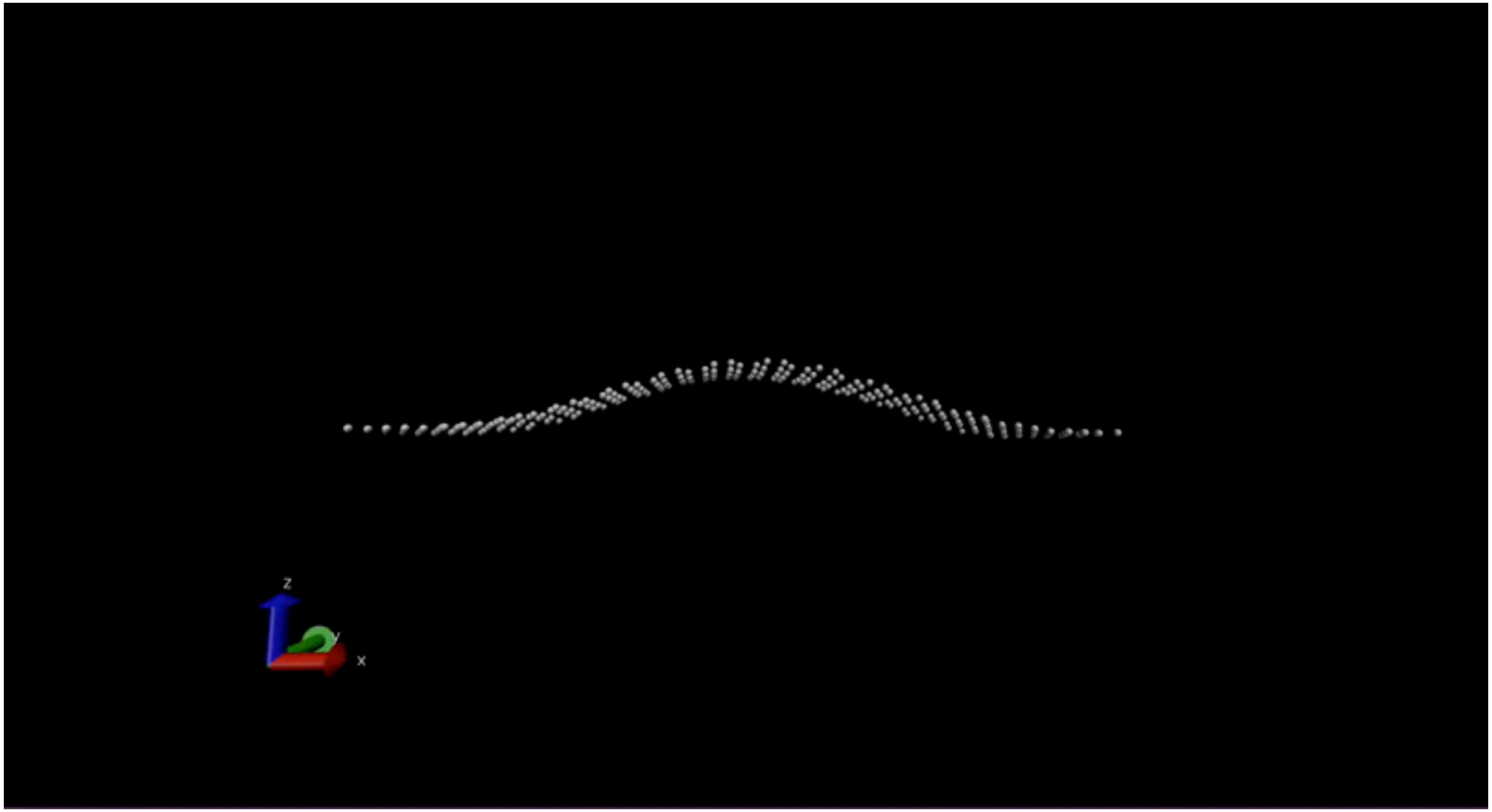


Switch protocol

Wrong way: apply the switch protocol from the wrong initial state



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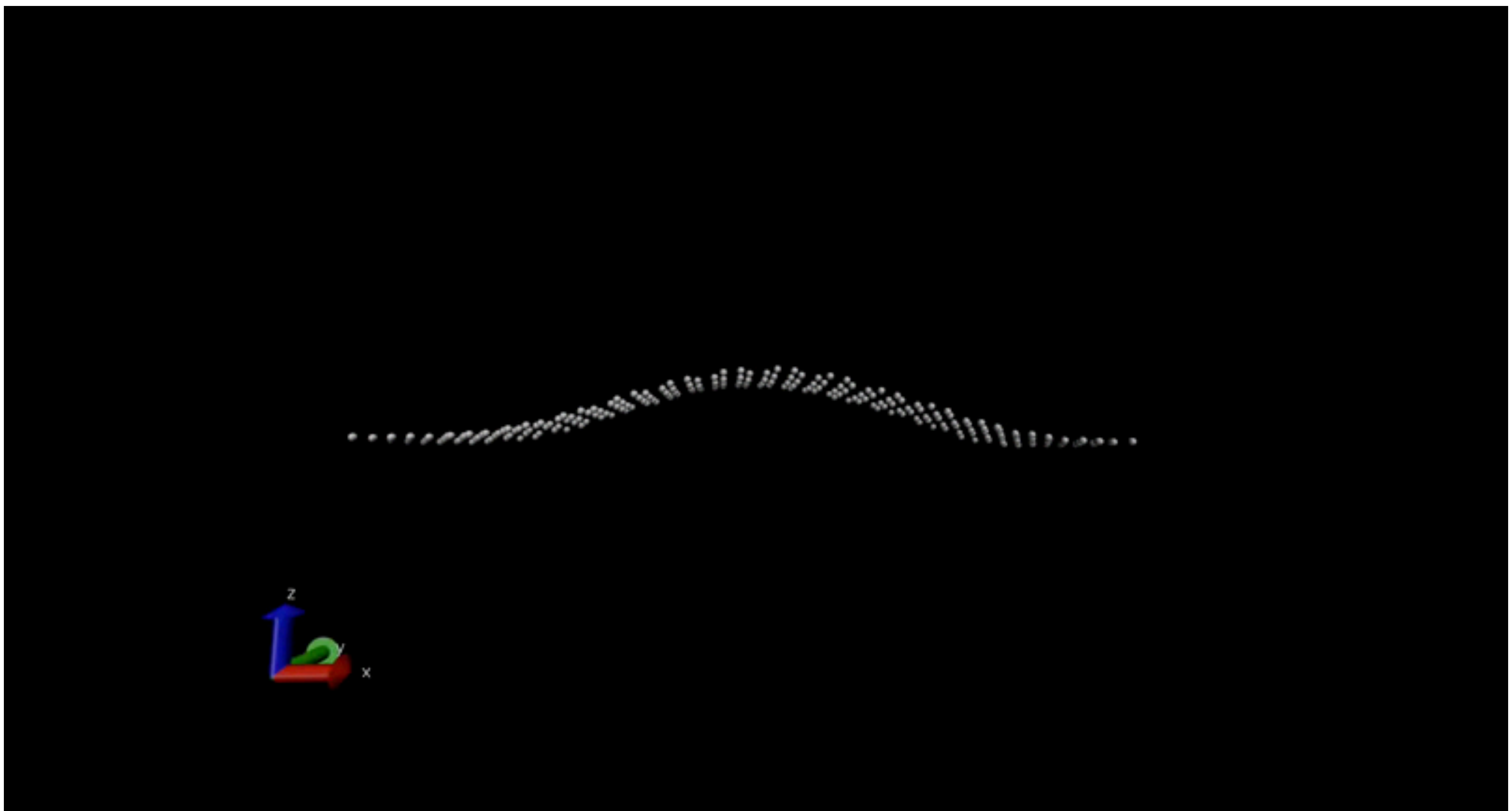

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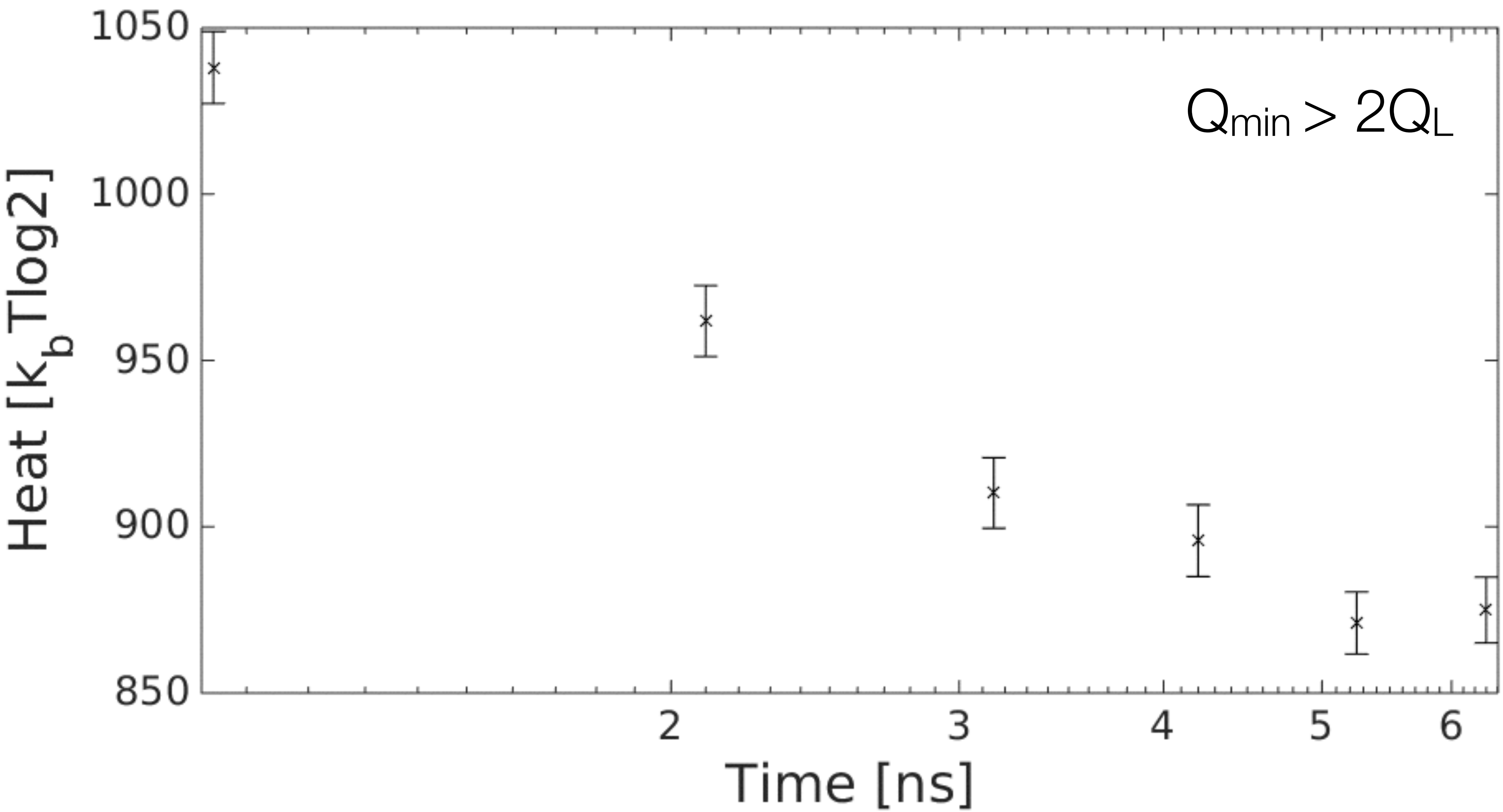

Thank you for your attention!

igor.neri@nipslab.org

NiPS Laboratory
Noise in Physical Systems

LANDAUER