Thermodynamic limits for approximate MEMS memory devices

Igor Neri, Miquel López-Suárez and Luca Gammaitoni

3rd Workshop On Approximate Computing, Stockholm, January 25, 2017

NiPS Laboratory
Noise in Physical Systems

MEMS Memory Devices

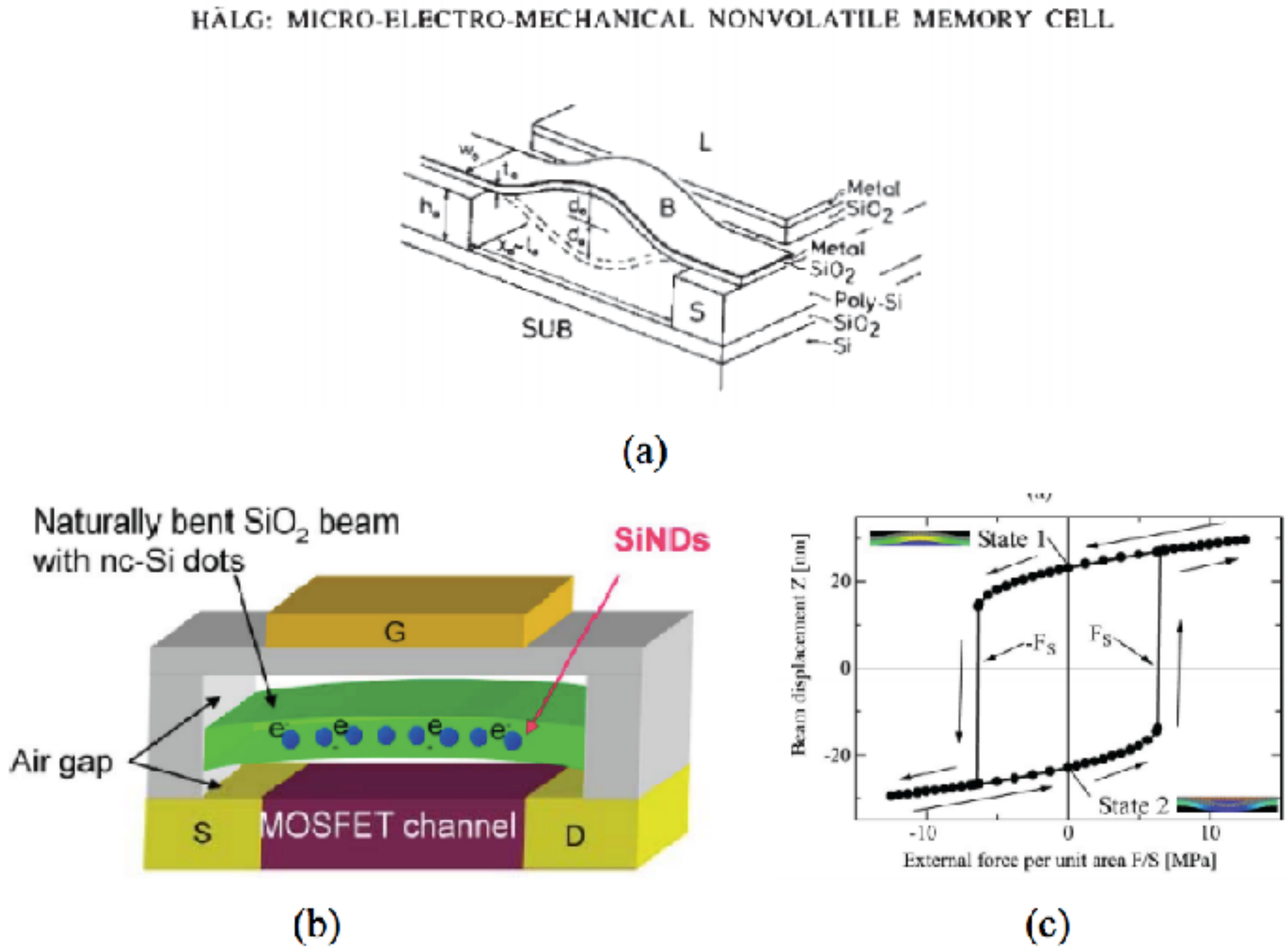
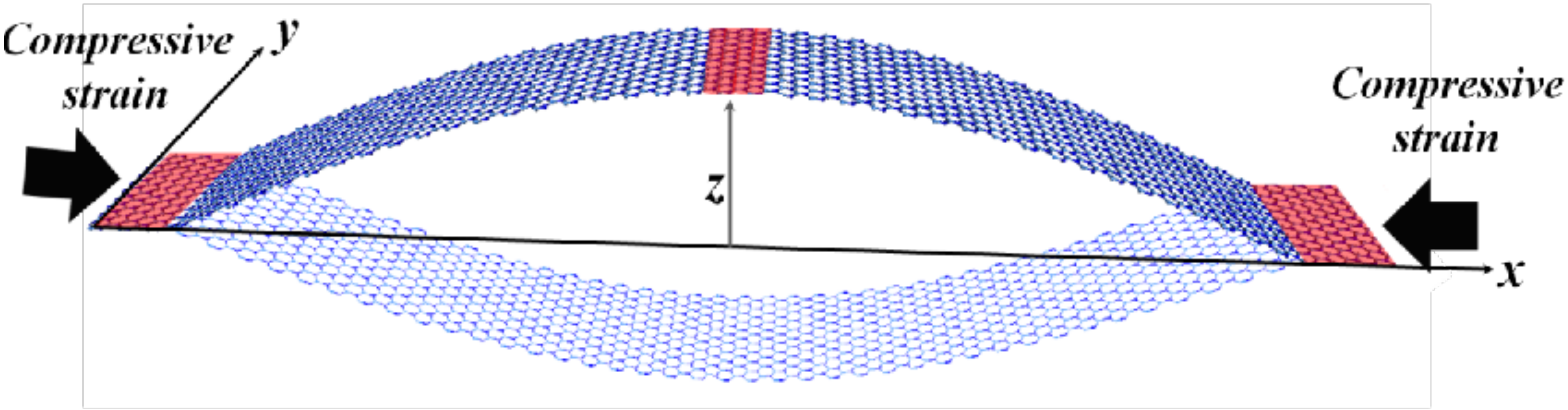
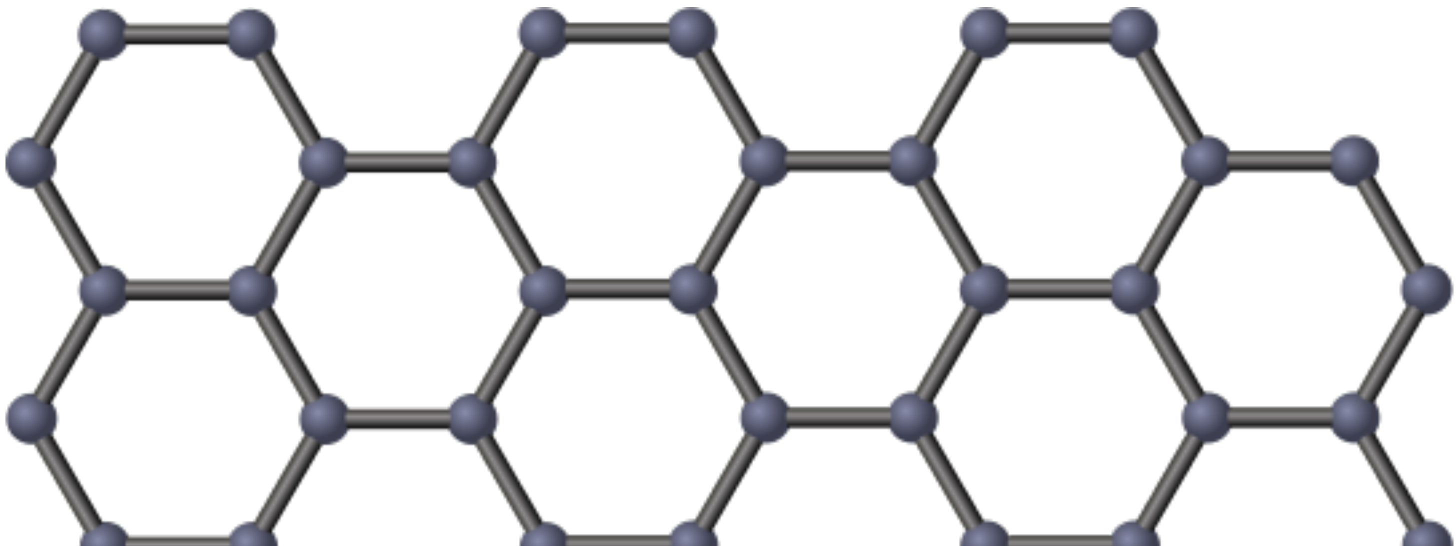


Figure 1: (a) Halg's and (b) Oda's bistable micro/nano-electro-mechanical memory concepts. (c) mechanical hysteresis in device (b).

Ionescu, Adrian M. "Nano-Electro-Mechanical (NEM) Memory Devices." Emerging Nanoelectronic Devices (2014): 123-136.

NEMS Memory Devices

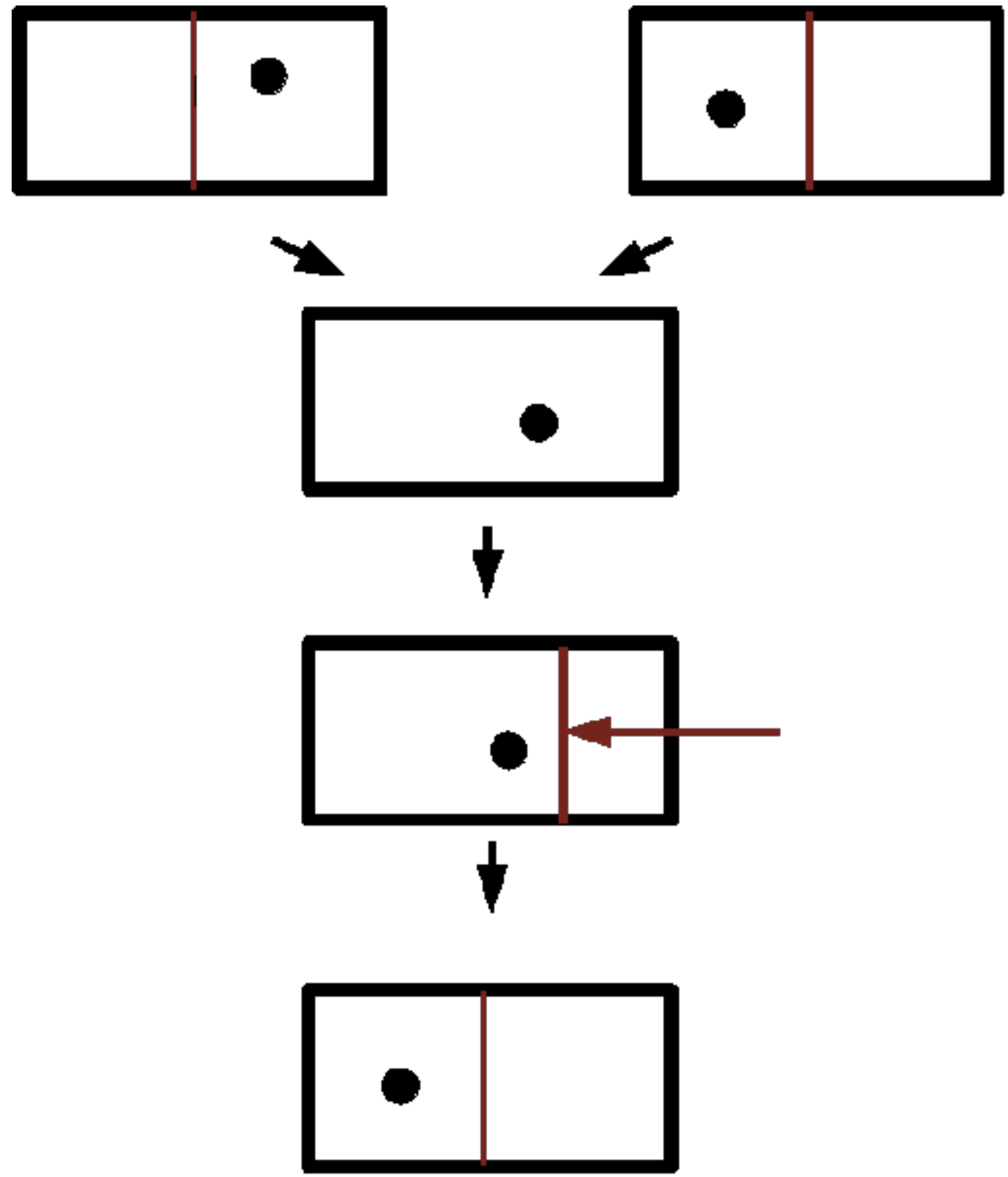




Neri, I., et al. "Reset and switch protocols at Landauer limit in a graphene buckled ribbon." EPL (Europhysics Letters) 111.1 (2015): 10004.

Landauer principle

- Minimum amount of energy required **greater than zero**
- Let assume the operation of **bit reset**
- # of initial states: 2
- # of final states: 1



Landauer principle

$$S = k_B \log W$$

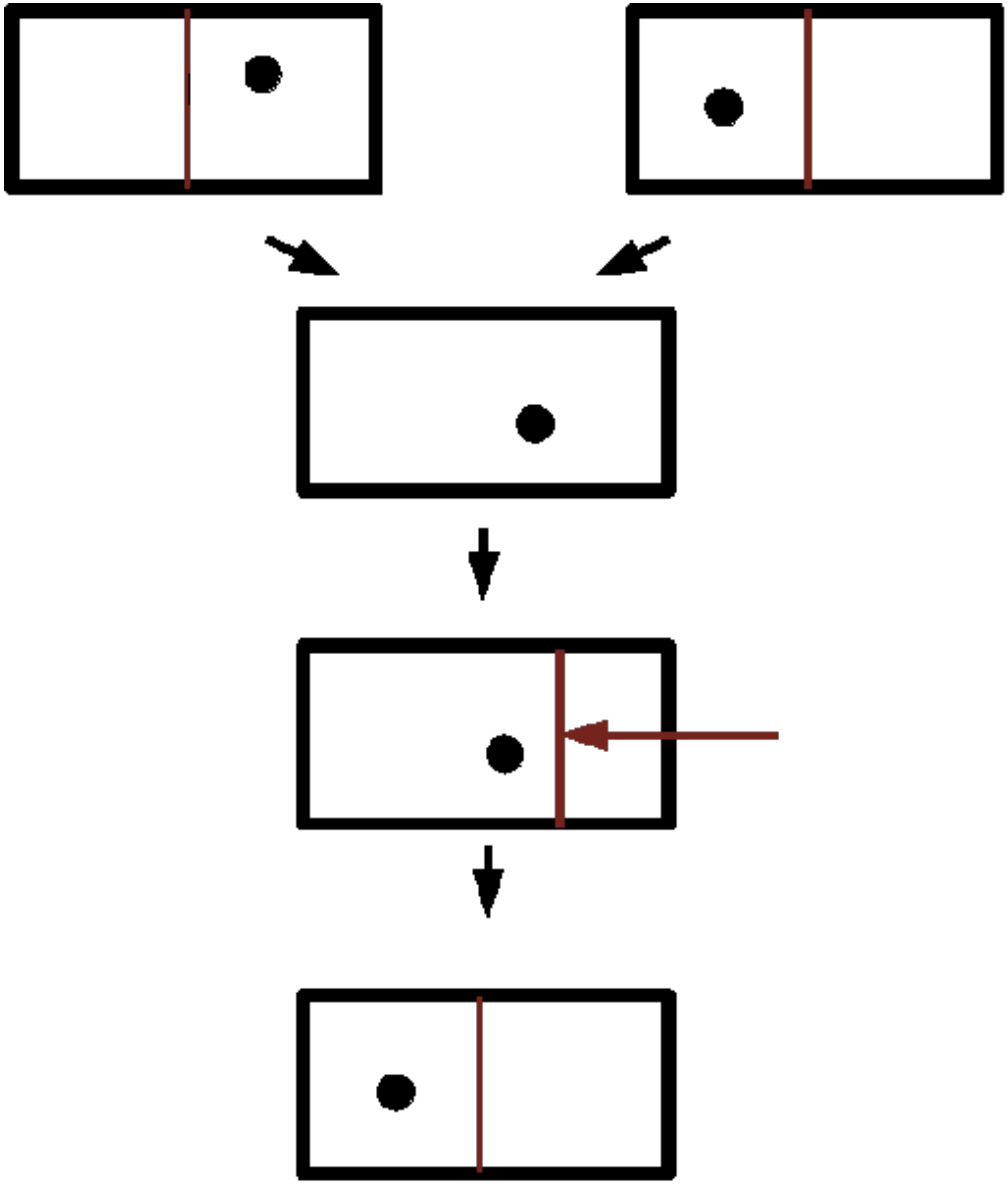
$$Q \leq T\Delta S$$

- Initial condition: two possible states $S_i = k_B \log 2$
- Final condition: one possible state $S_f = k_B \log 1$

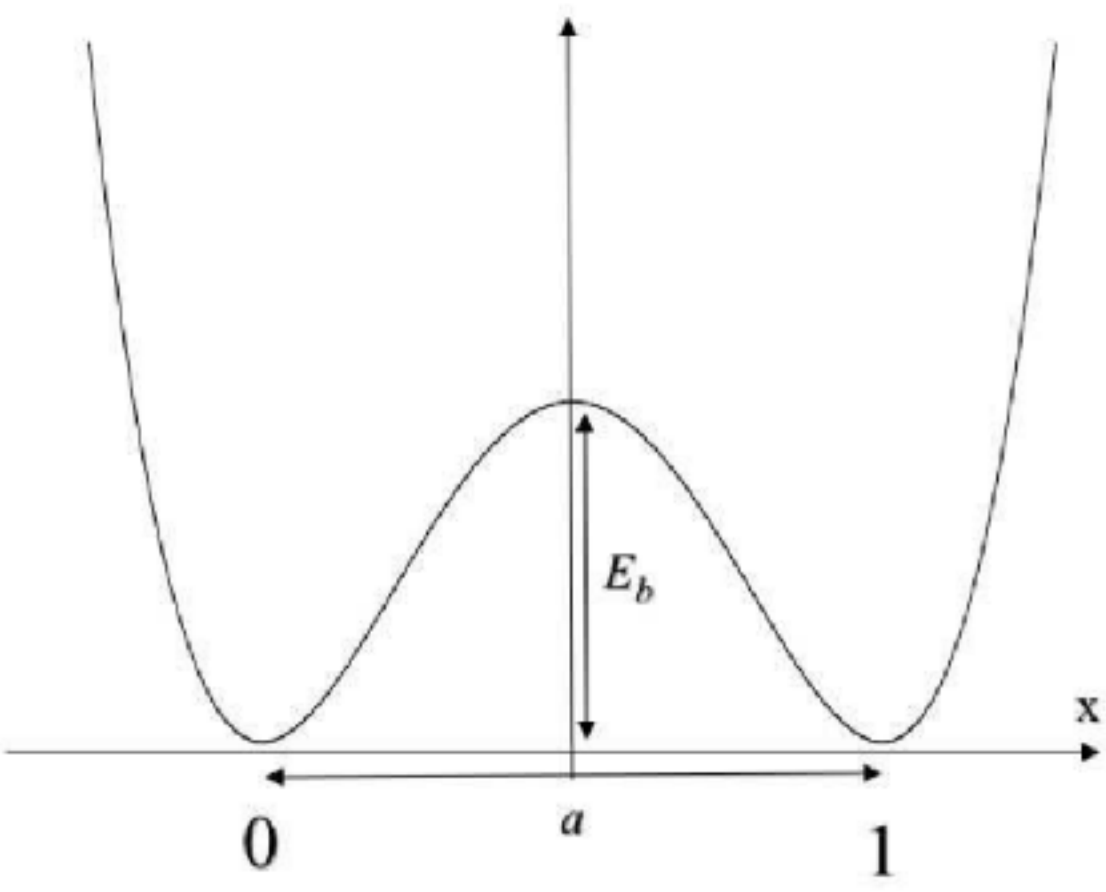
$$\Delta S = S_f - S_i = -k_B \log 2$$

- Heat produced

$$Q \leq T\Delta S = -k_B T \log 2$$



Landauer principle with error: theory



Beating the Landauer's limit by trading energy with uncertainty - L. Gammaitoni - arXiv:1111.2937 [cond-mat.mtrl-sci]

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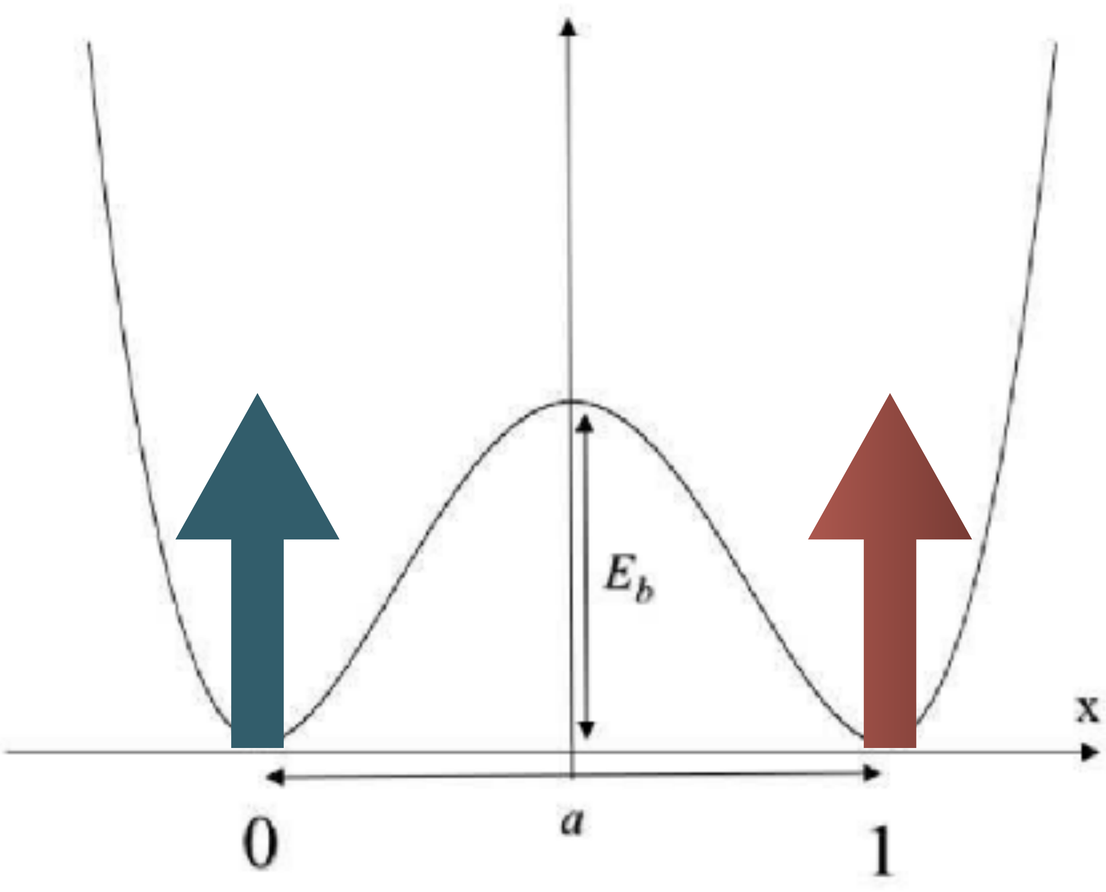

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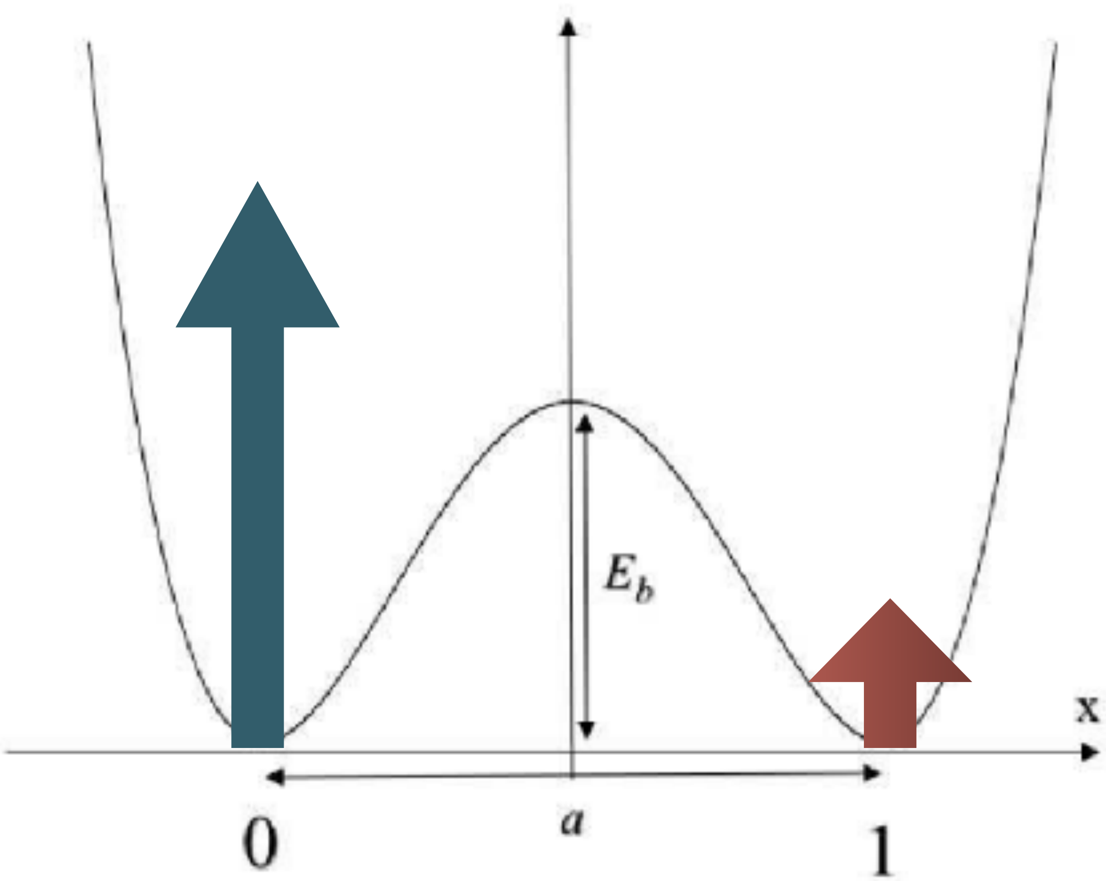

$$\Delta S = S_f - S_i$$

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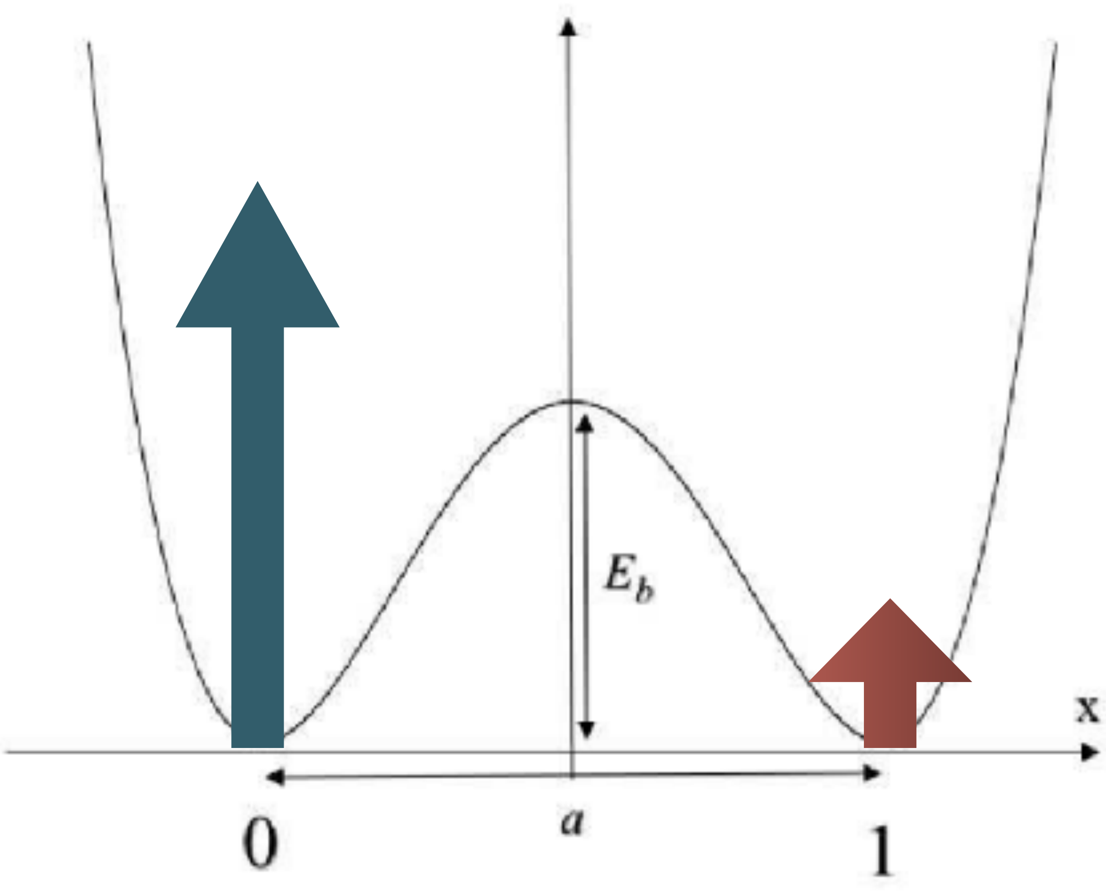

$$\Delta S = S_f - S_i$$

$$S_f(P_e) = -k_B((1 - P_e)\ln(1 - P_e) + P_e \ln(P_e))$$

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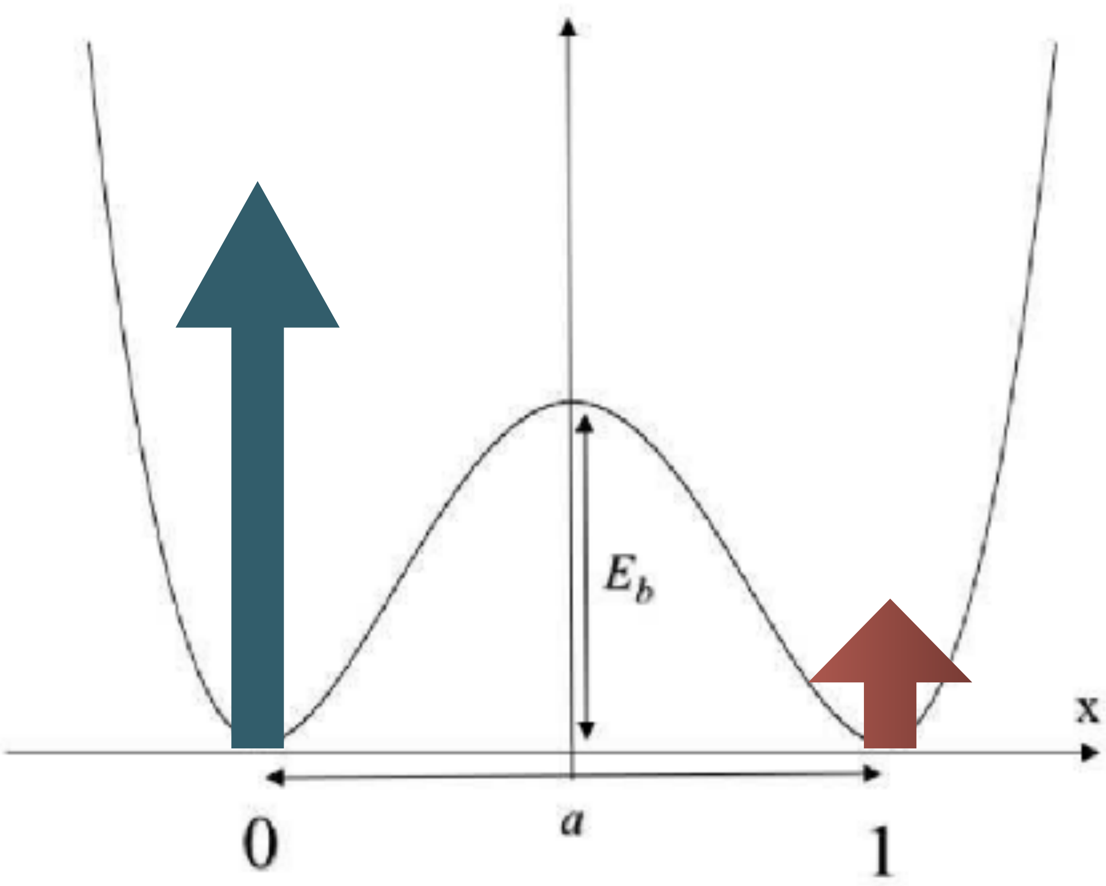

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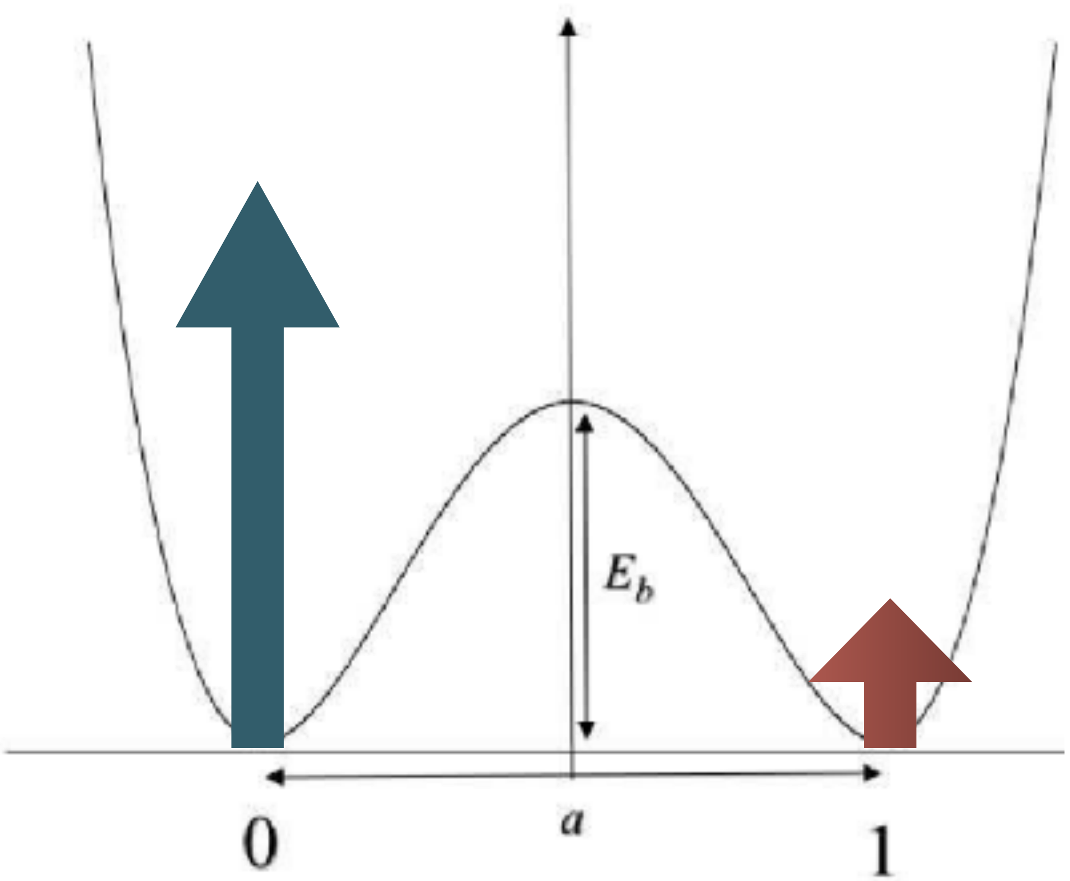

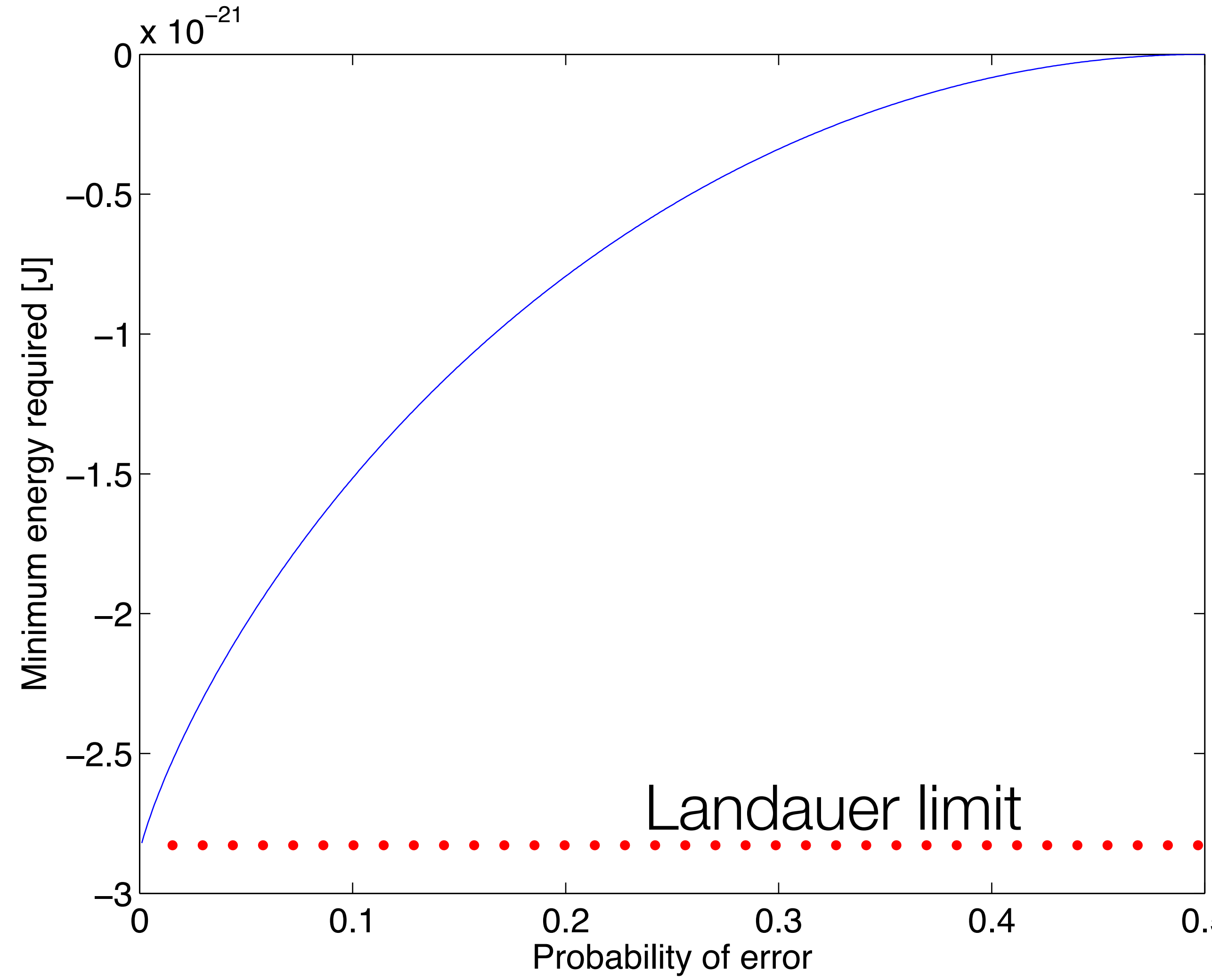

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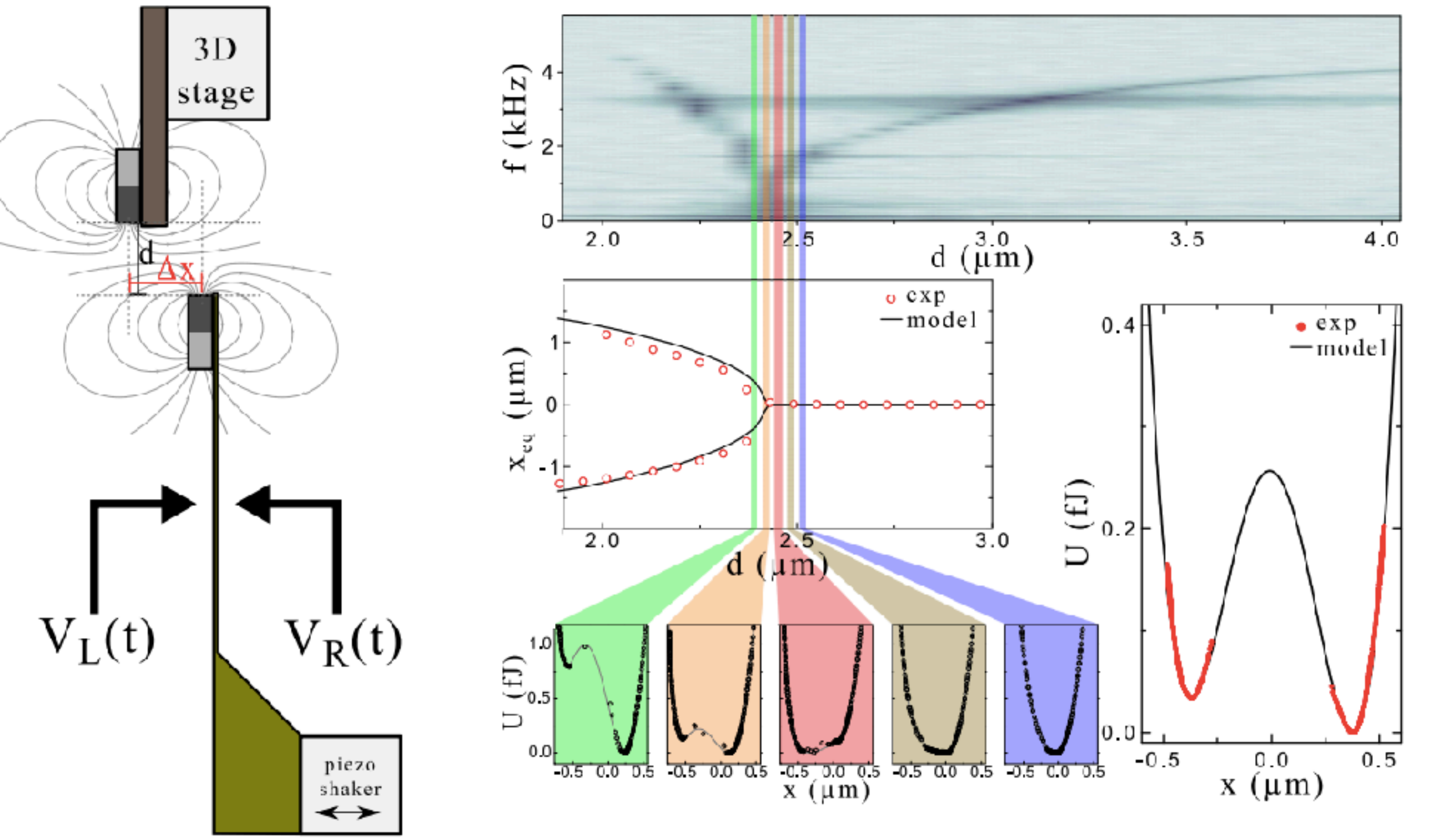
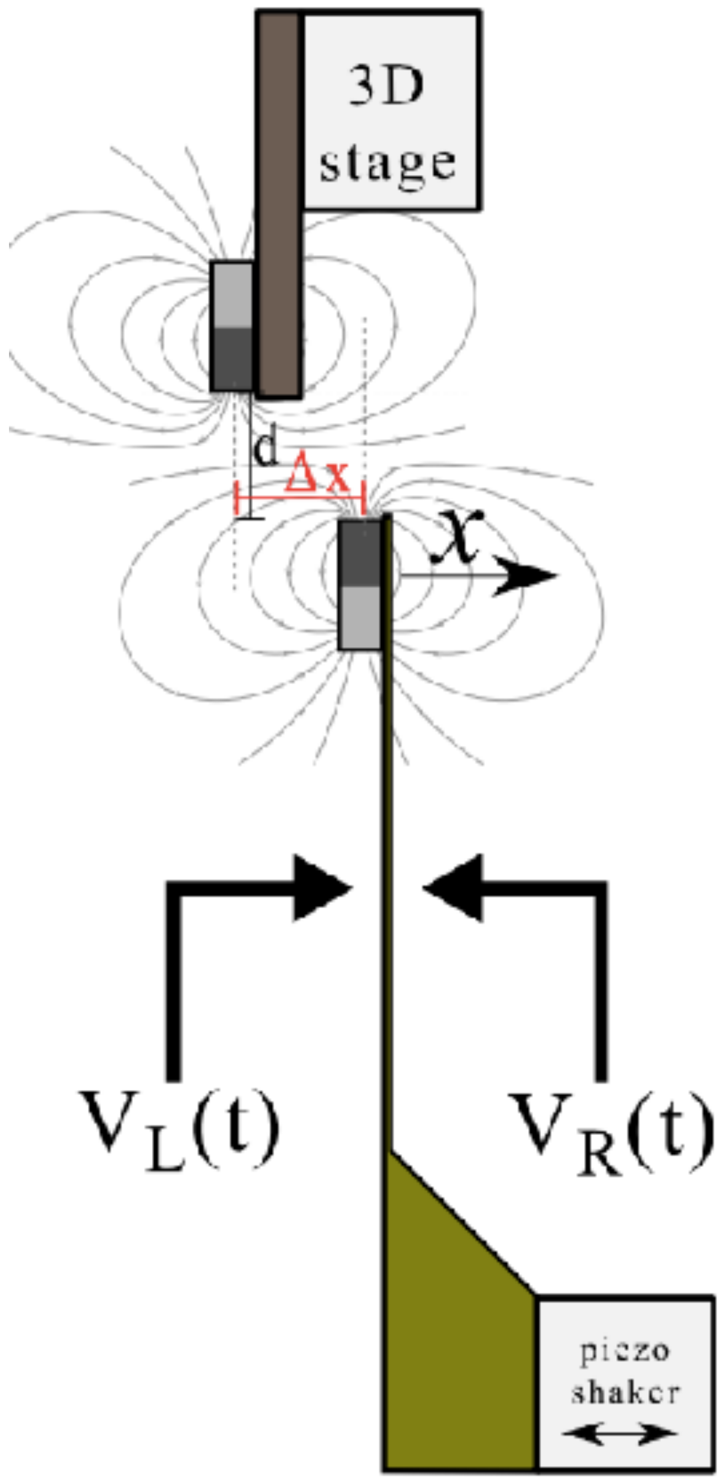
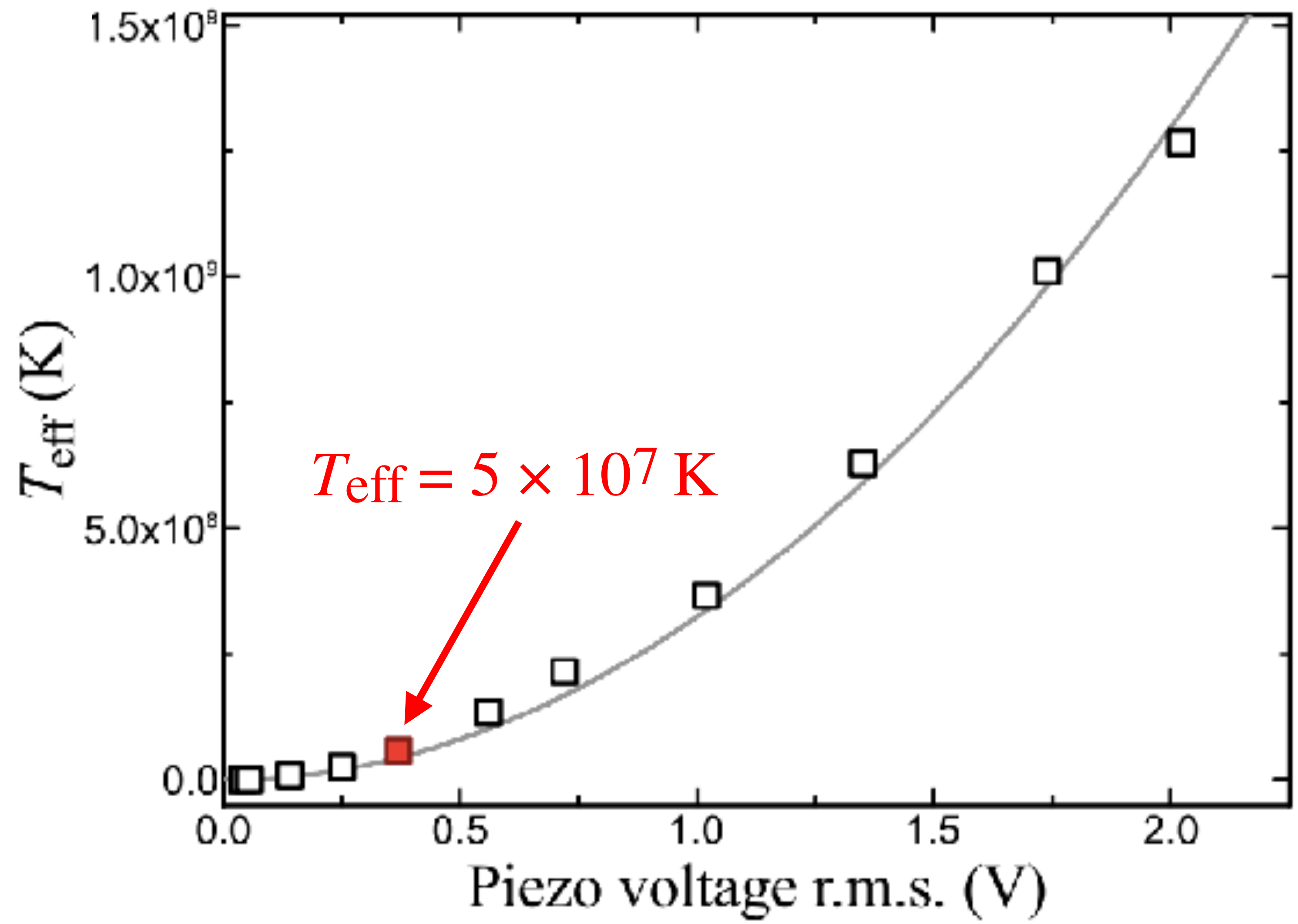
Micro-electromechanical memory bit based on magnetic repulsion



Micro-electromechanical memory bit based on magnetic repulsion, López-Suárez, Miquel and Neri, Igor, Applied Physics Letters, 109, 133505 (2016)

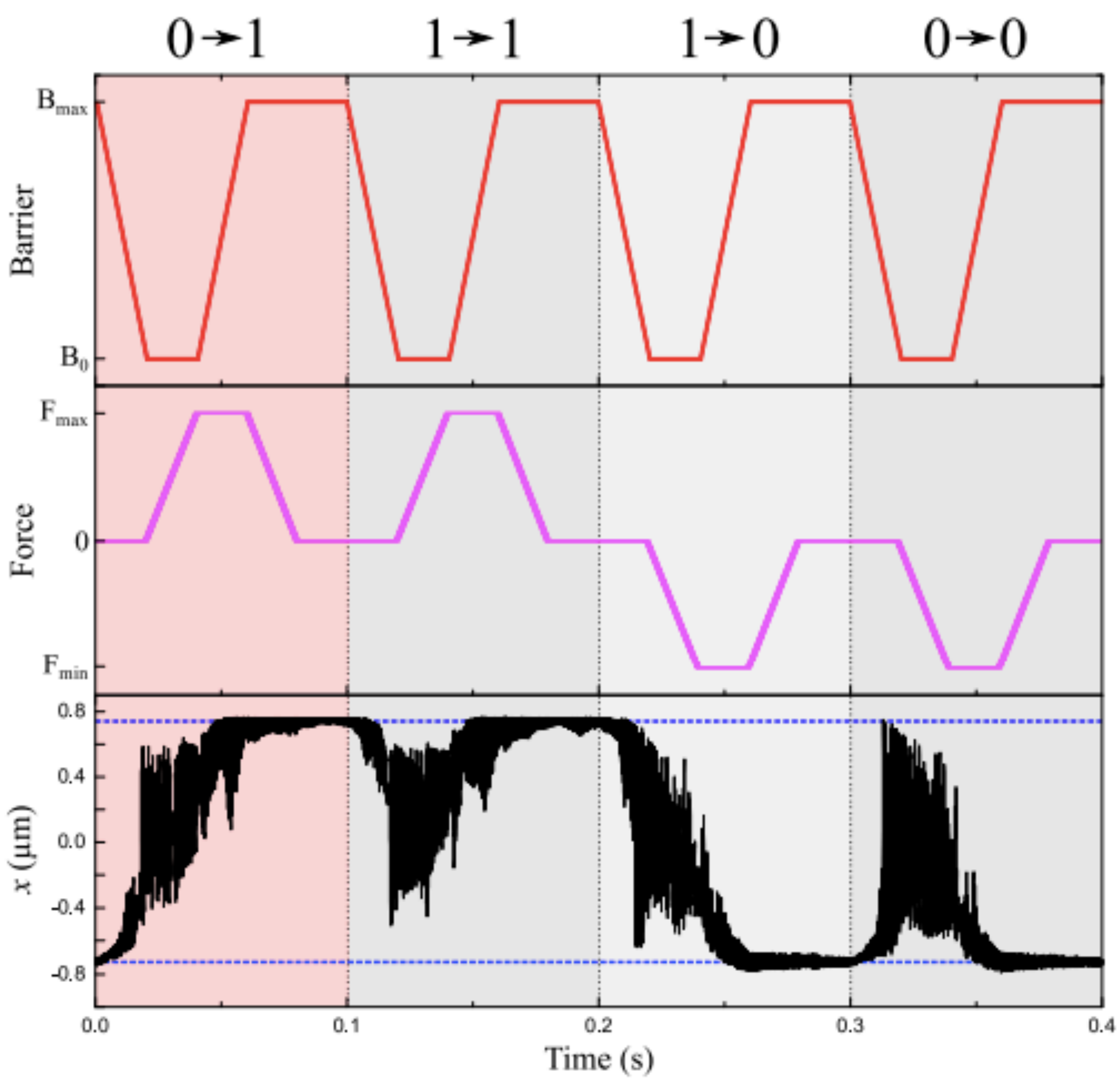
Micro-electromechanical memory bit based on magnetic repulsion

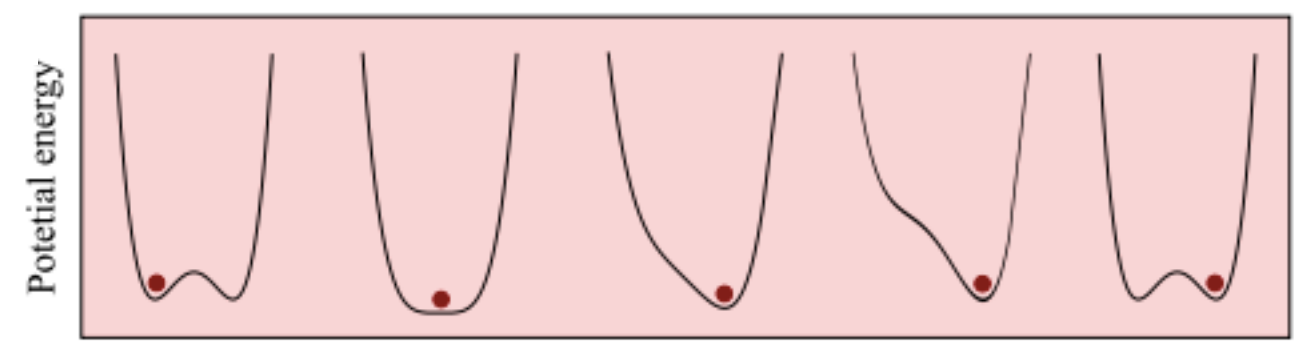




Neri, Igor, and Miquel López-Suárez. "Heat production and error probability relation in Landauer reset at effective temperature." Scientific Reports 6 (2016).

Reset protocol





Steps for reset from '0' to '1'

$$W = \int_0^{\tau_p} \sum_{k=1}^{M} \frac{\partial U(x, \boldsymbol{\lambda})}{\partial \lambda_k} \frac{\partial \lambda_k}{\partial t} \mathrm{d}t$$

Q=W-ΔU

$$Q(P_s) \geq k_B T \left[\ln(2) + P_s \ln(P_s) + (1 - P_s) \ln(1 - P_s)\right]$$

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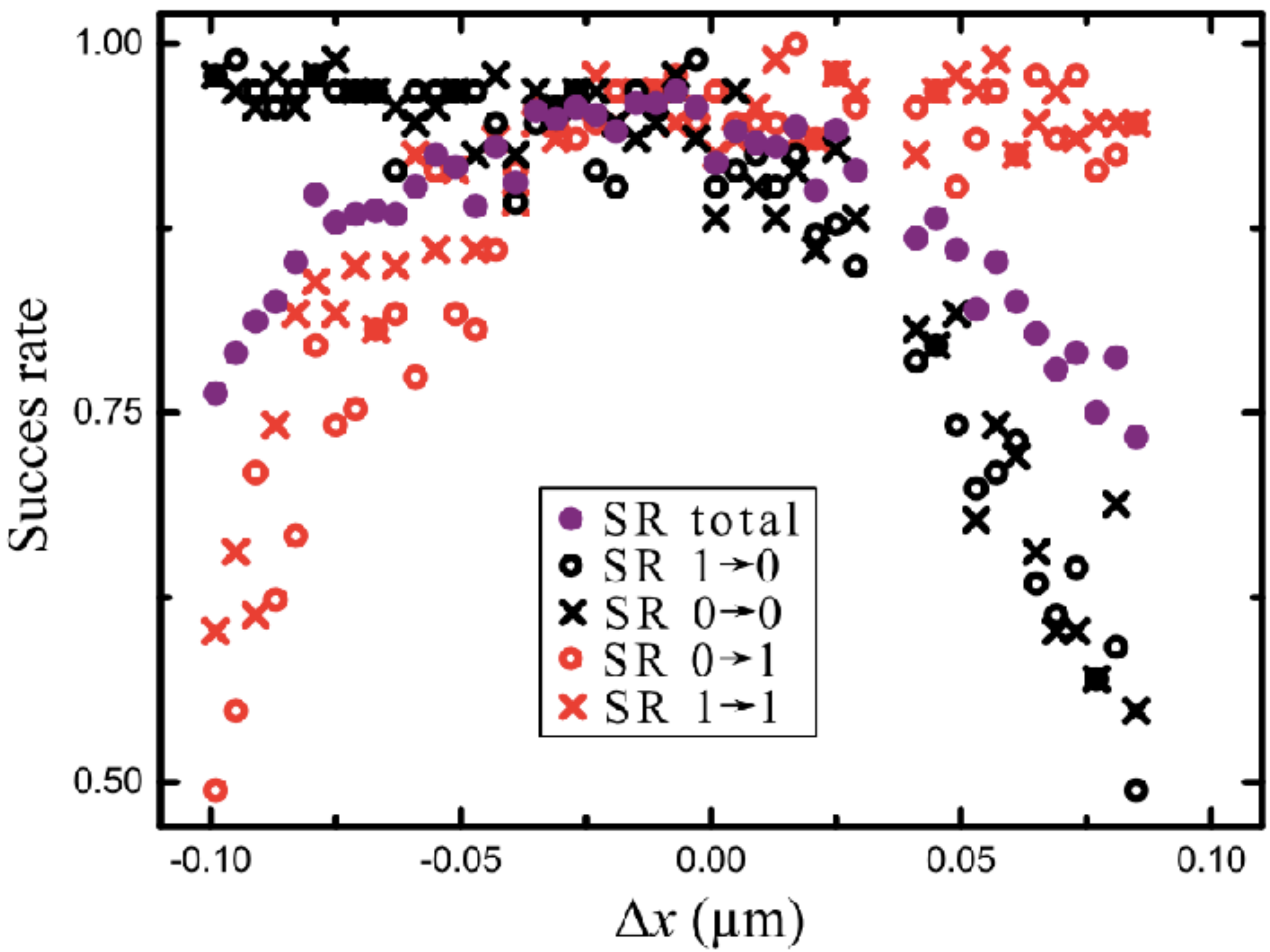
Landauer principle with error: experimental data



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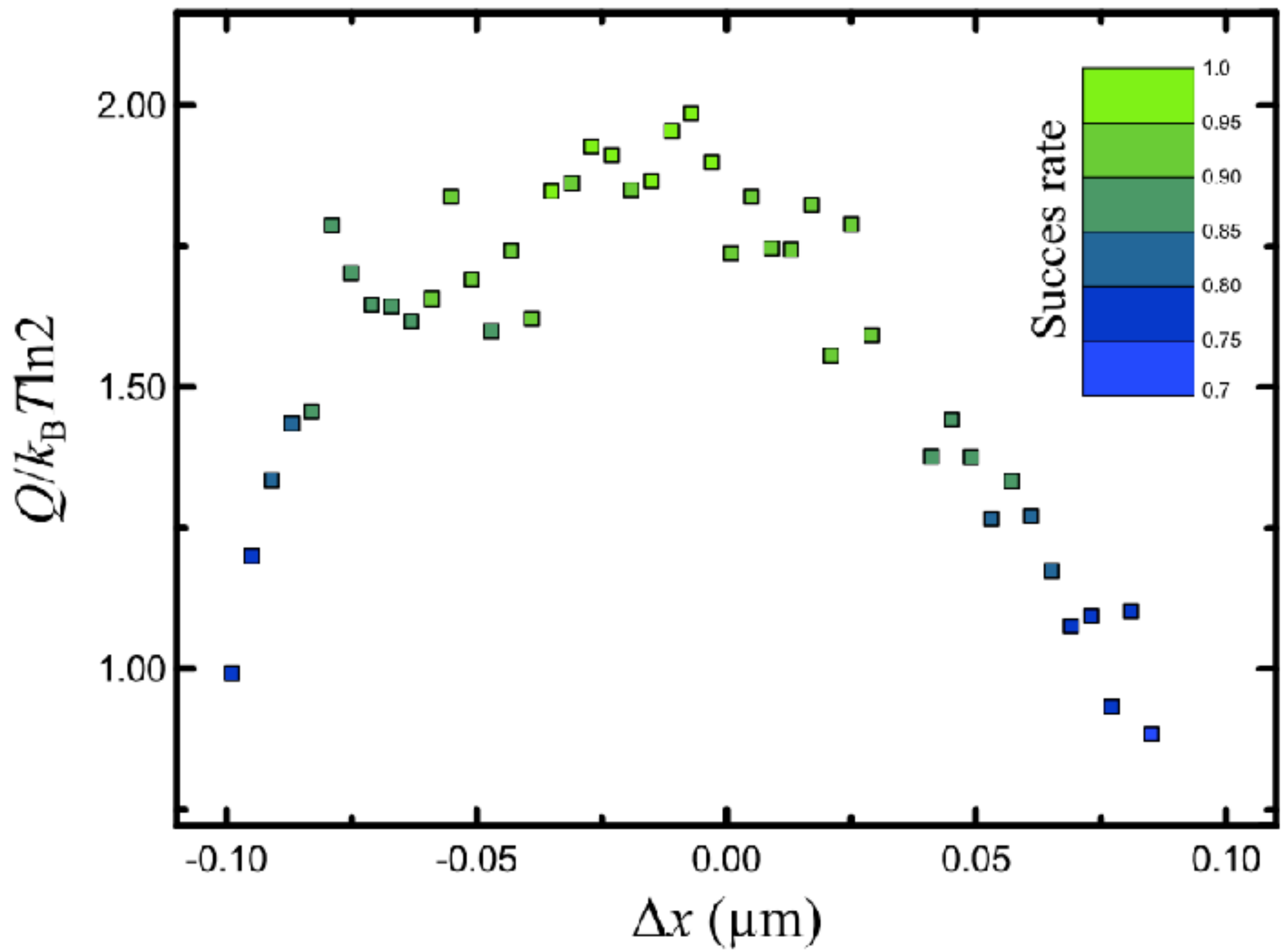

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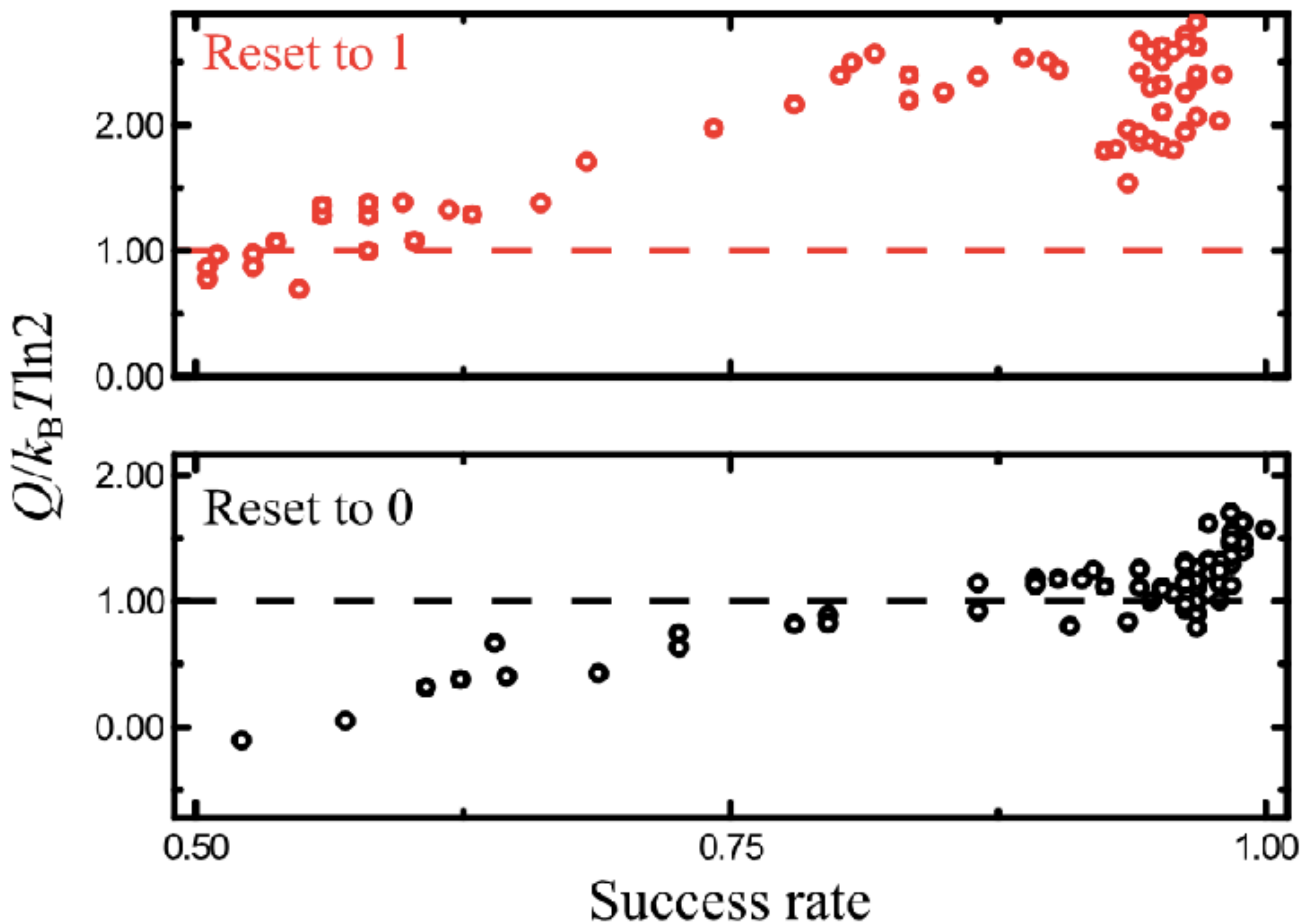

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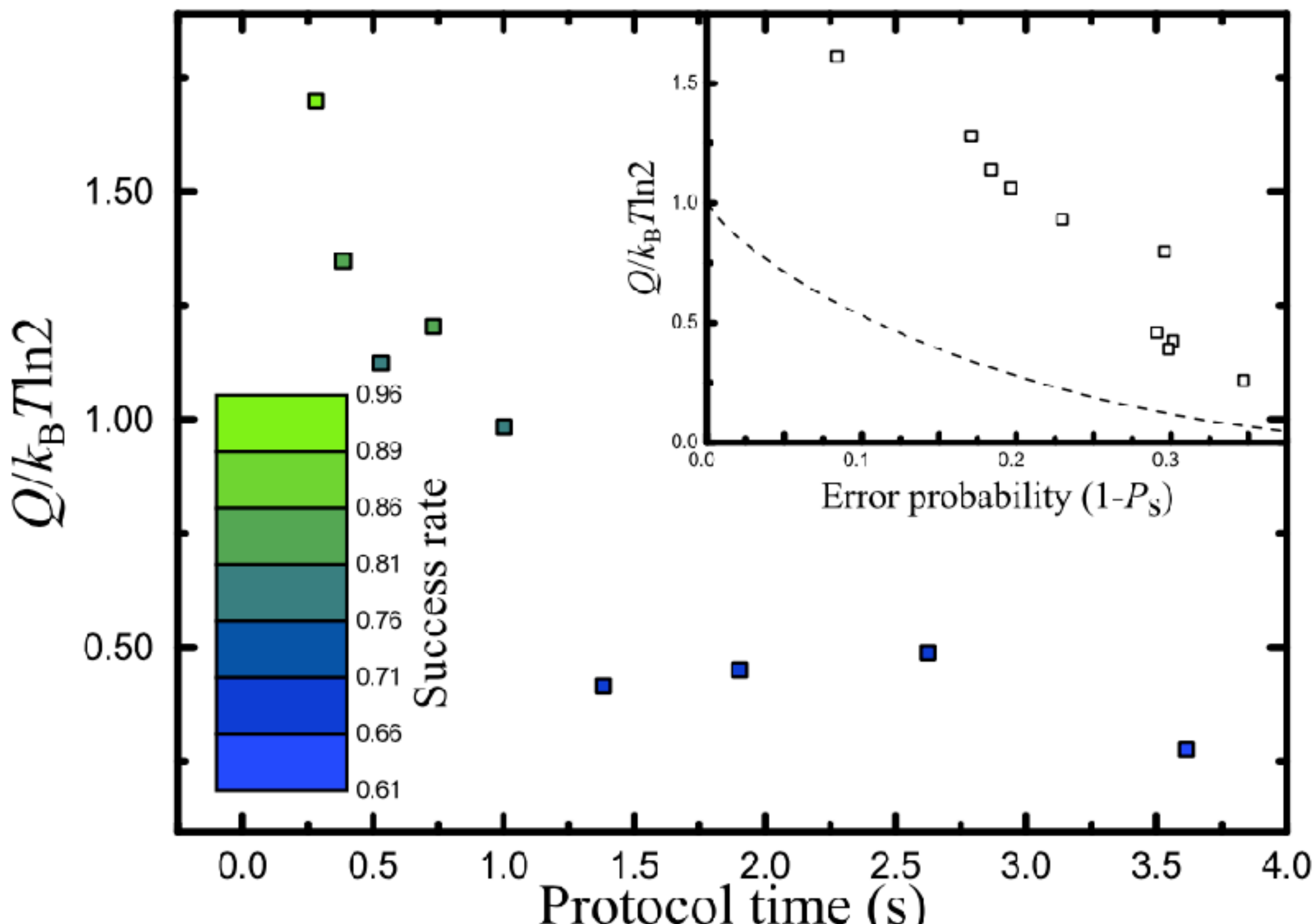

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Thank you for your attention!

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