UNIVERSITÀ DEGLI STUDI
DI PERUGIA

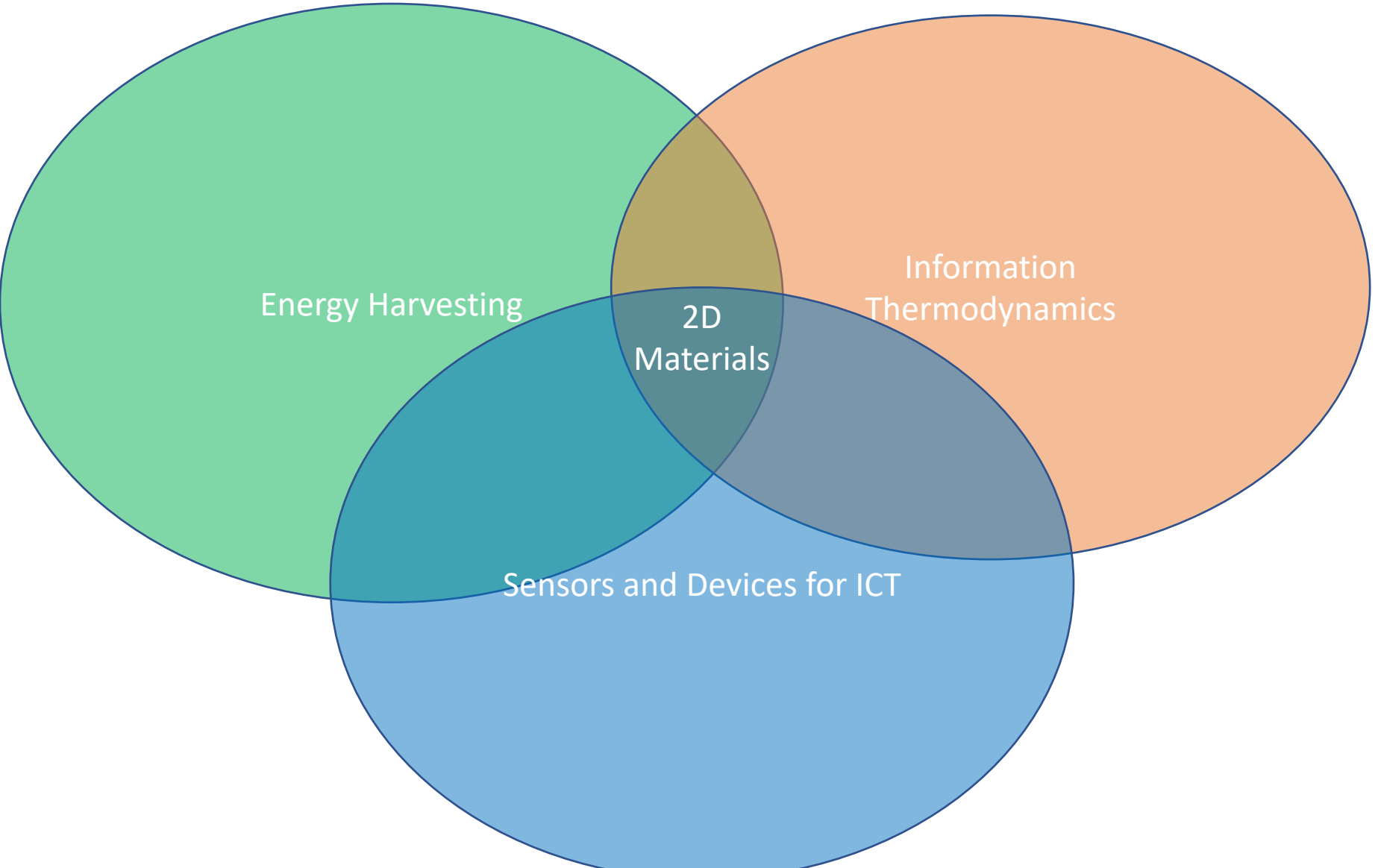
NiPS Laboratory
Noise in Physical Systems

Studio delle proprietà elettroniche ed ottiche di materiali bidimensionali

Igor Neri

PHP2020 - Physics Highlights Perugia 2020/21 – 27 Ottobre 2020

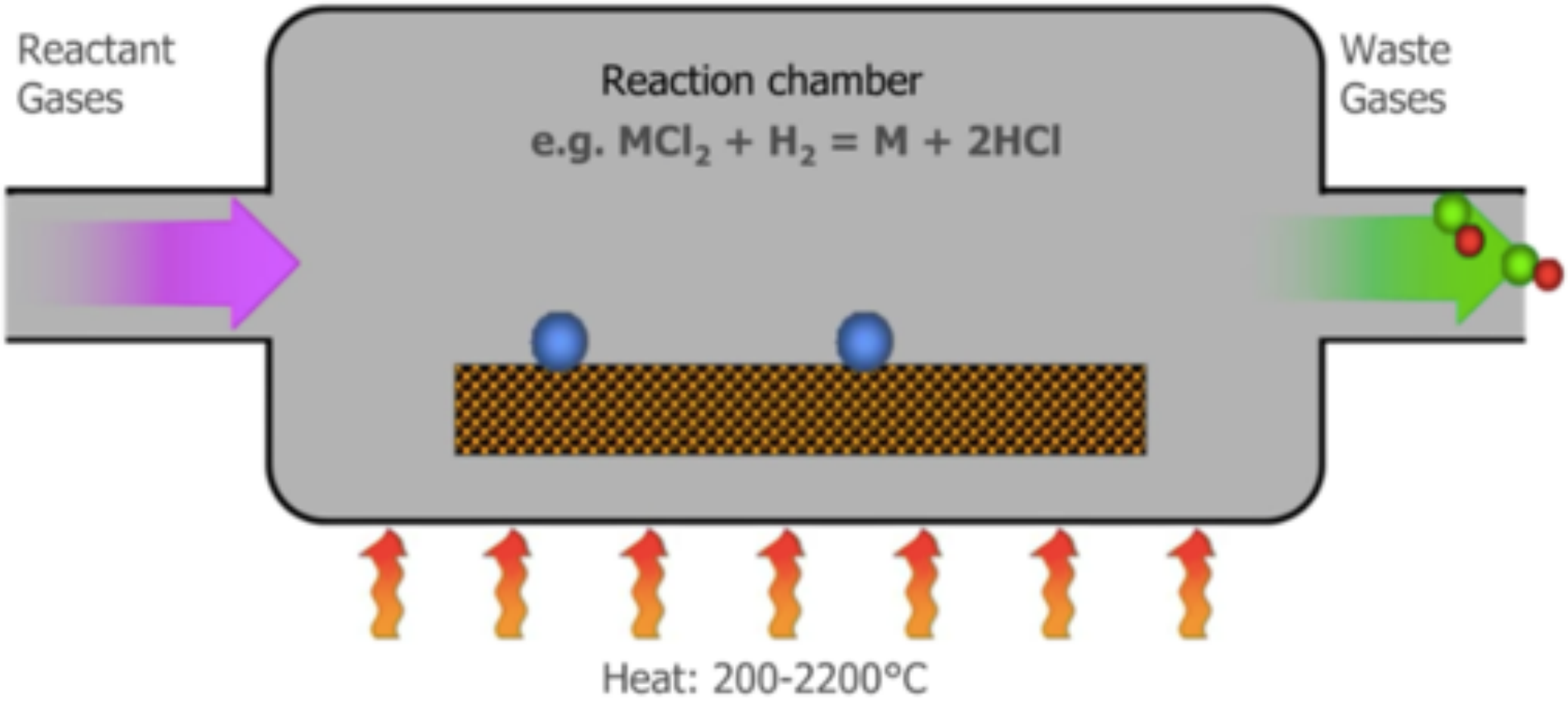
Research Activities



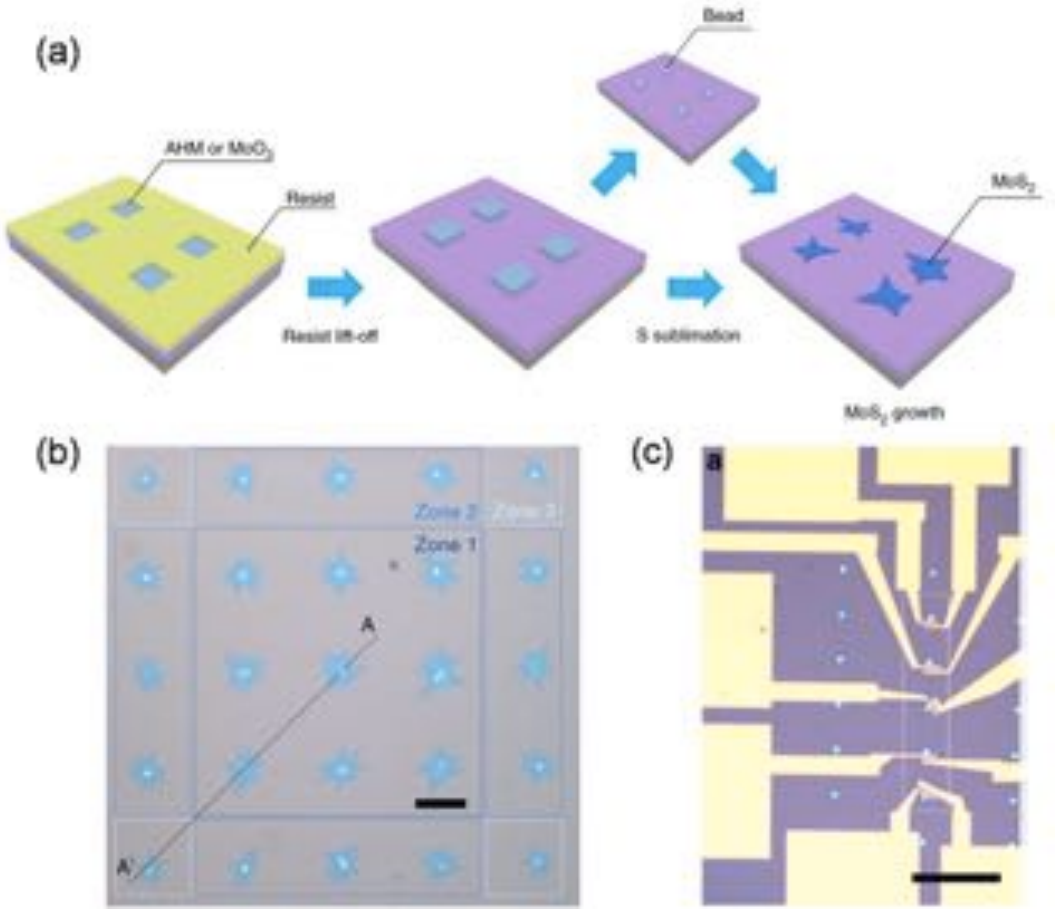
Outline

- Preparation techniques
- Thickness measurements
- Electronic properties
- Fast thickness identification
- Applications
  - Strain sensors
  - NEMS memories
  - Heat rectifier

Preparation techniques
1) Chemical Vapor Deposition

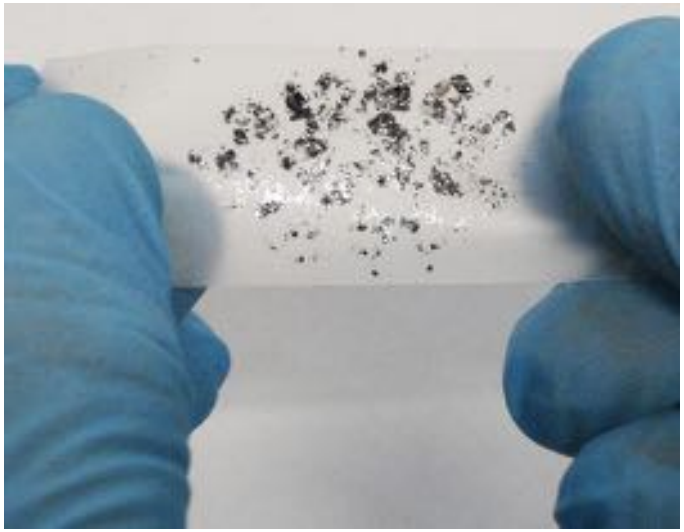


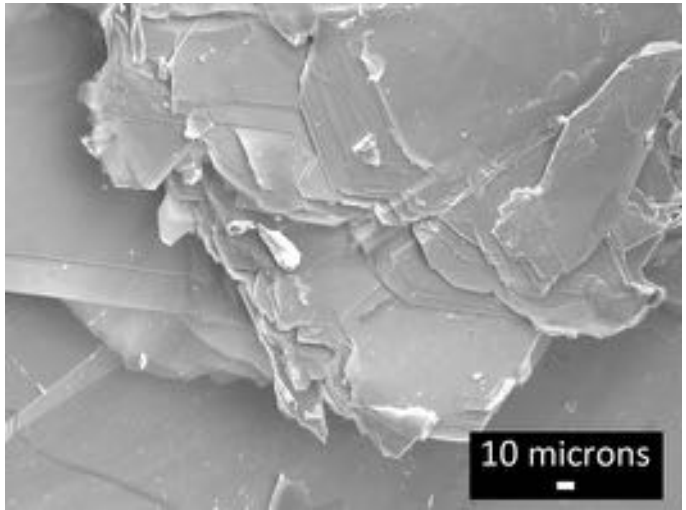
Preparation techniques
2) Metal-Guided Selective Growth

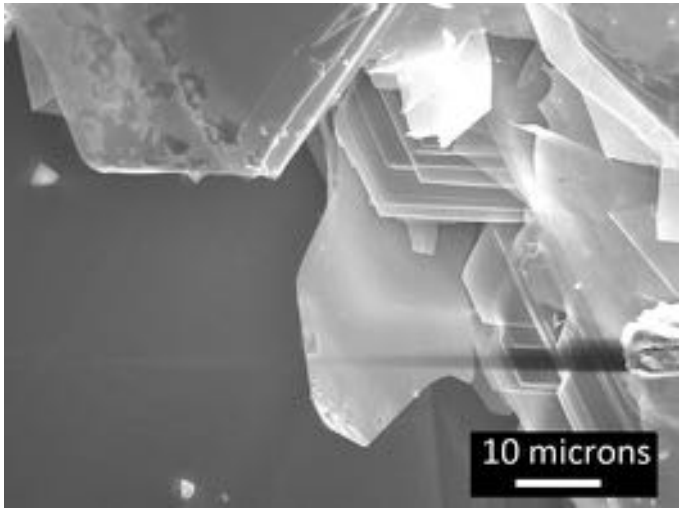


Li, Jiantong, and Mikael Östling. "Scalable fabrication of 2D semiconducting crystals for future electronics." *Electronics* 4.4 (2015): 1033-1061.

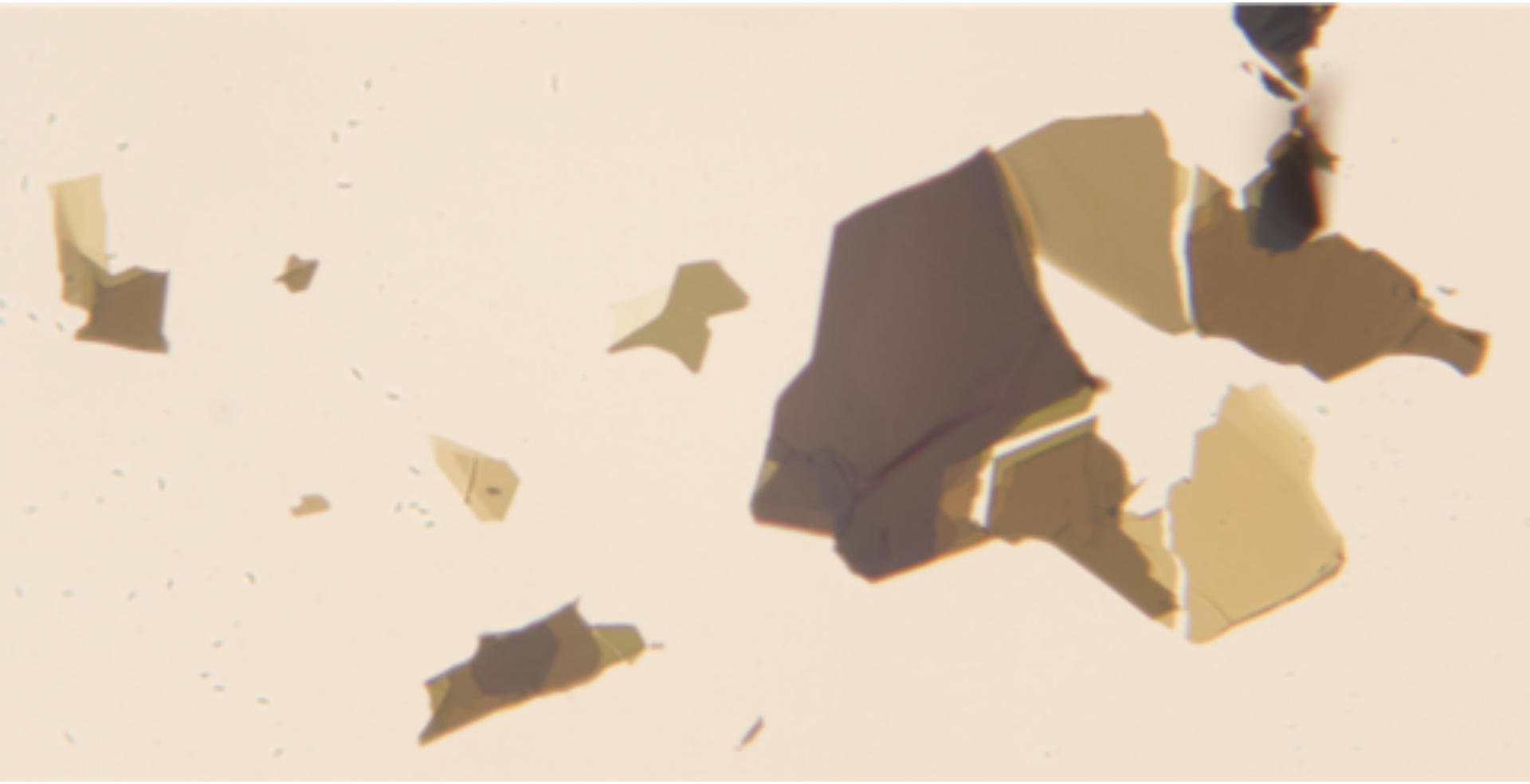
Preparation techniques
3) Mechanical Exfoliation





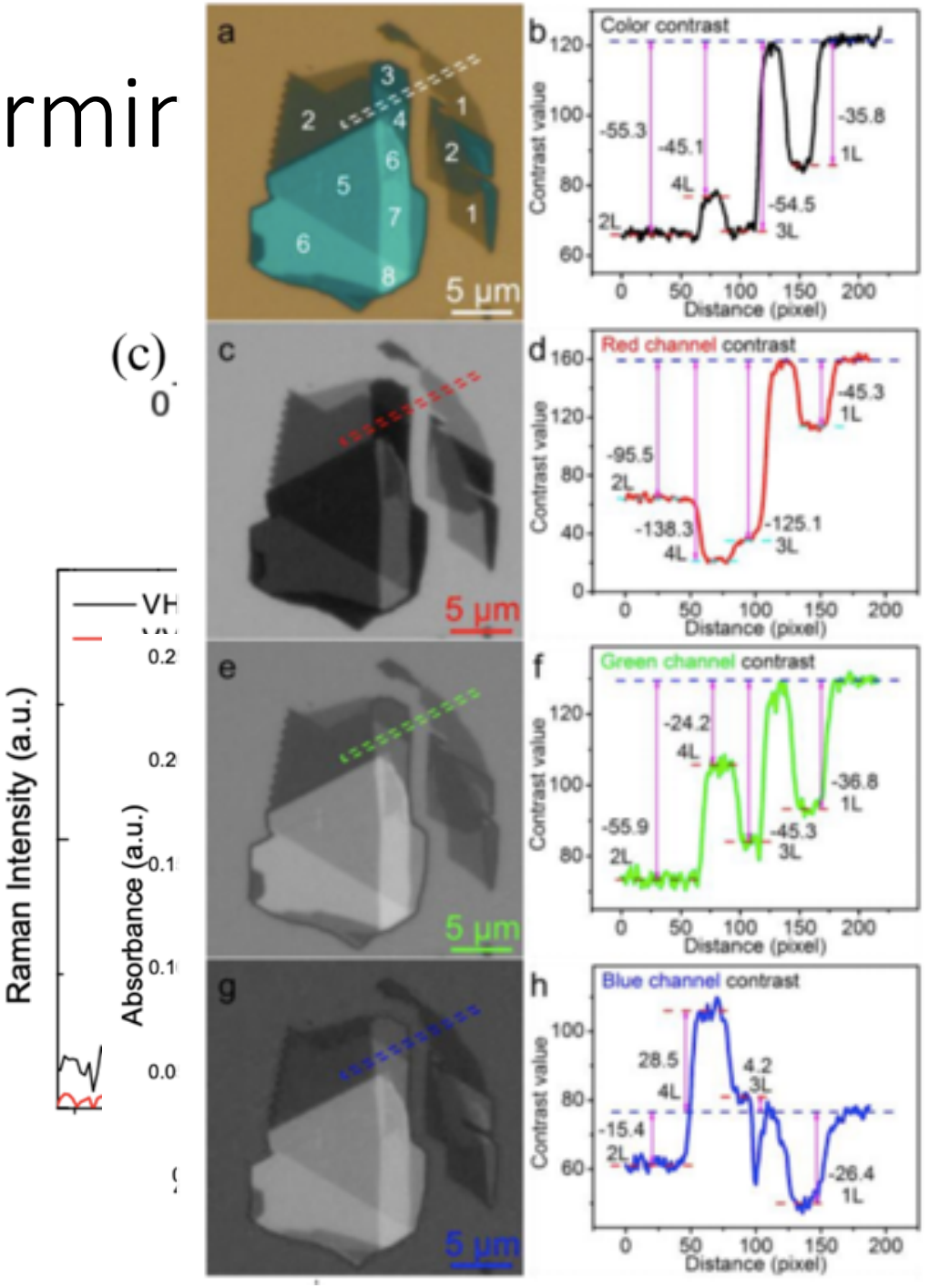


Thickness determination
layers

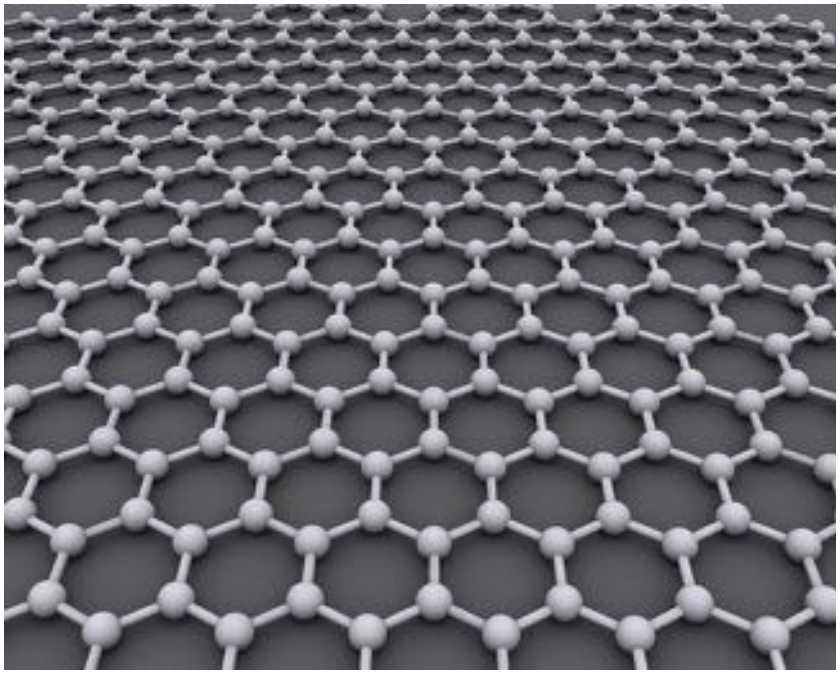


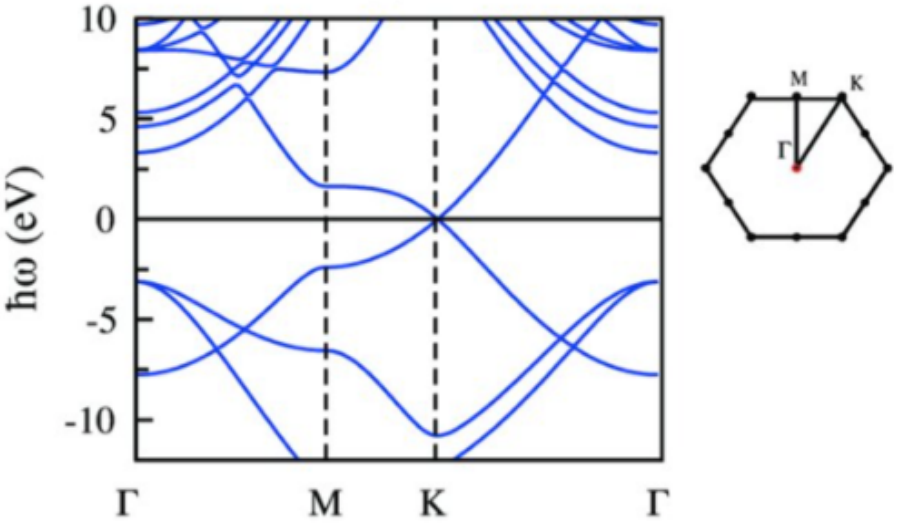
Thickness determir # layers

- AFM measurements
- Raman Spectroscopy
- Absorbance
- Image analysis

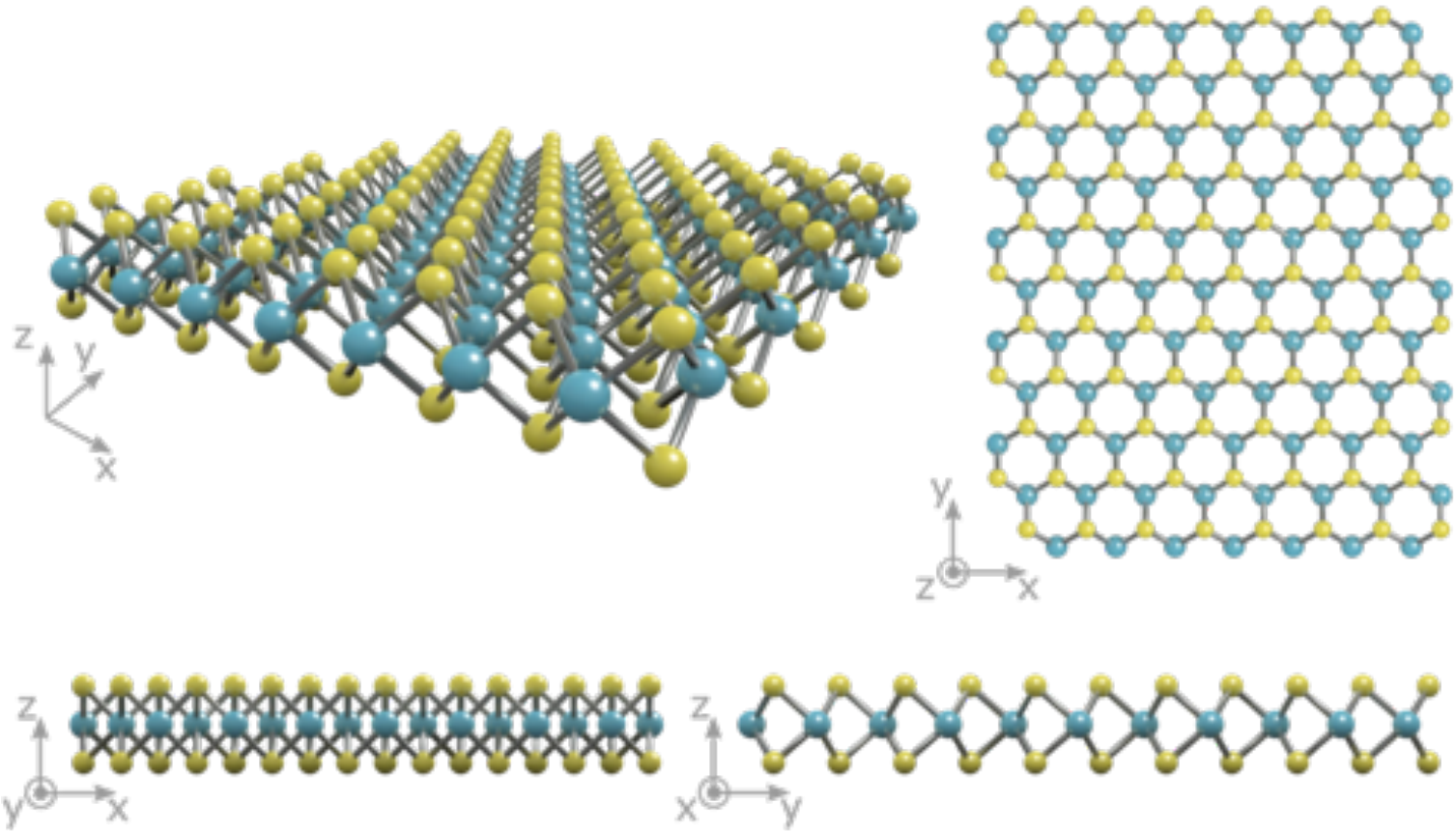


Graphene





Molybdenum disulfide - MoS_2



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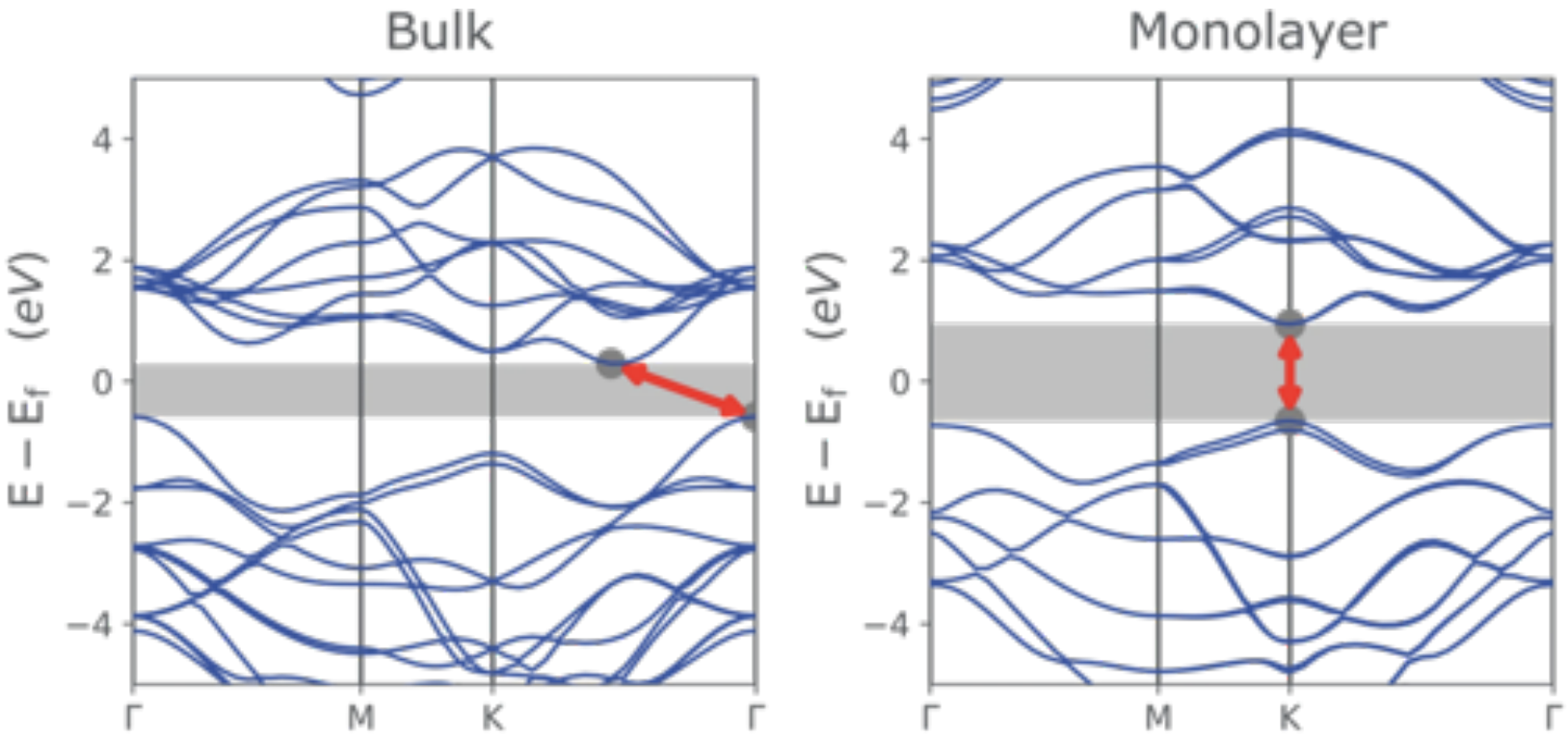
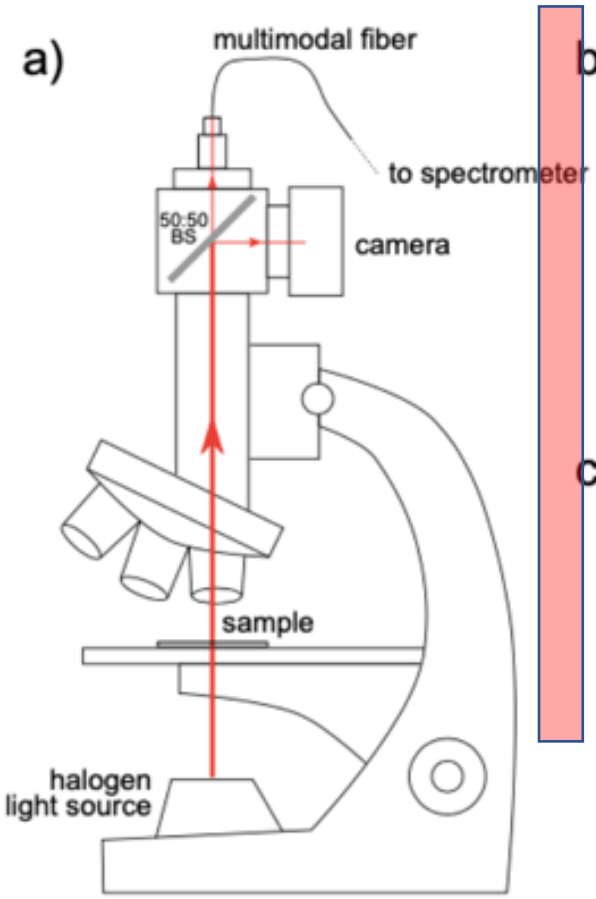
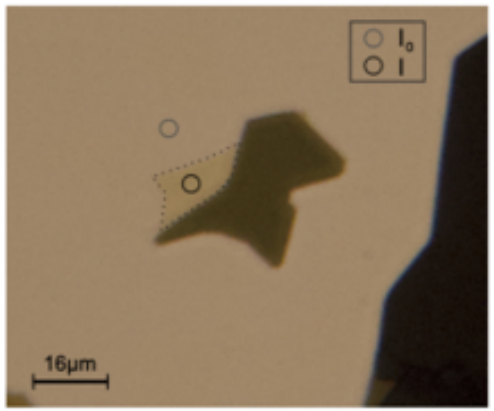
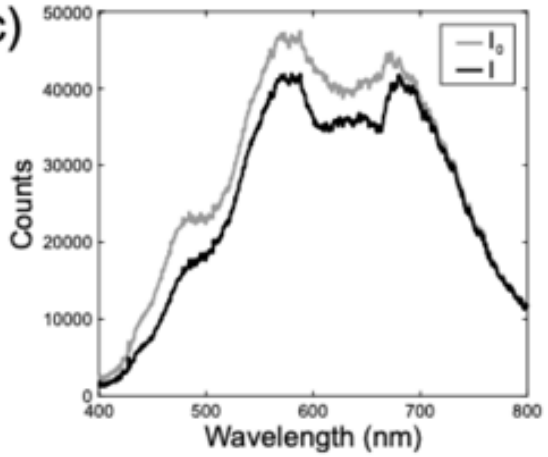


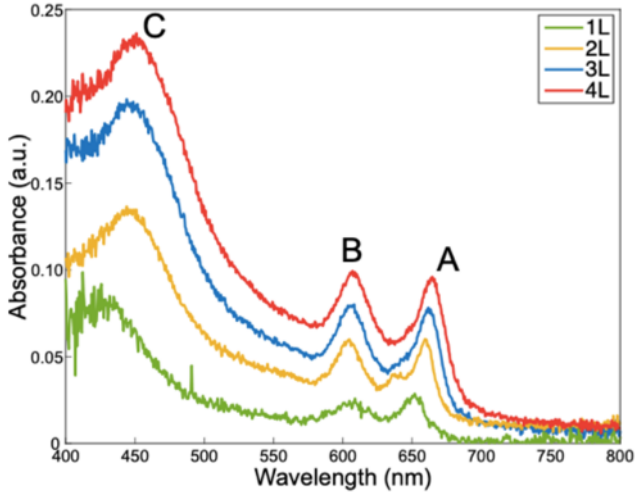
Fast MoS2 thickness identification by transmission imaging

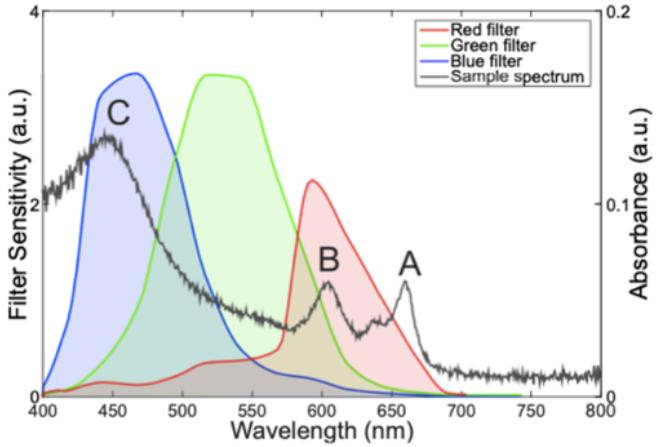
Fast MoS2 thickness identification by transmission imaging











I. Neri et al. "Fast MoS2 thickness identification by transmission imaging" *Applied Nanoscience (in press)*.

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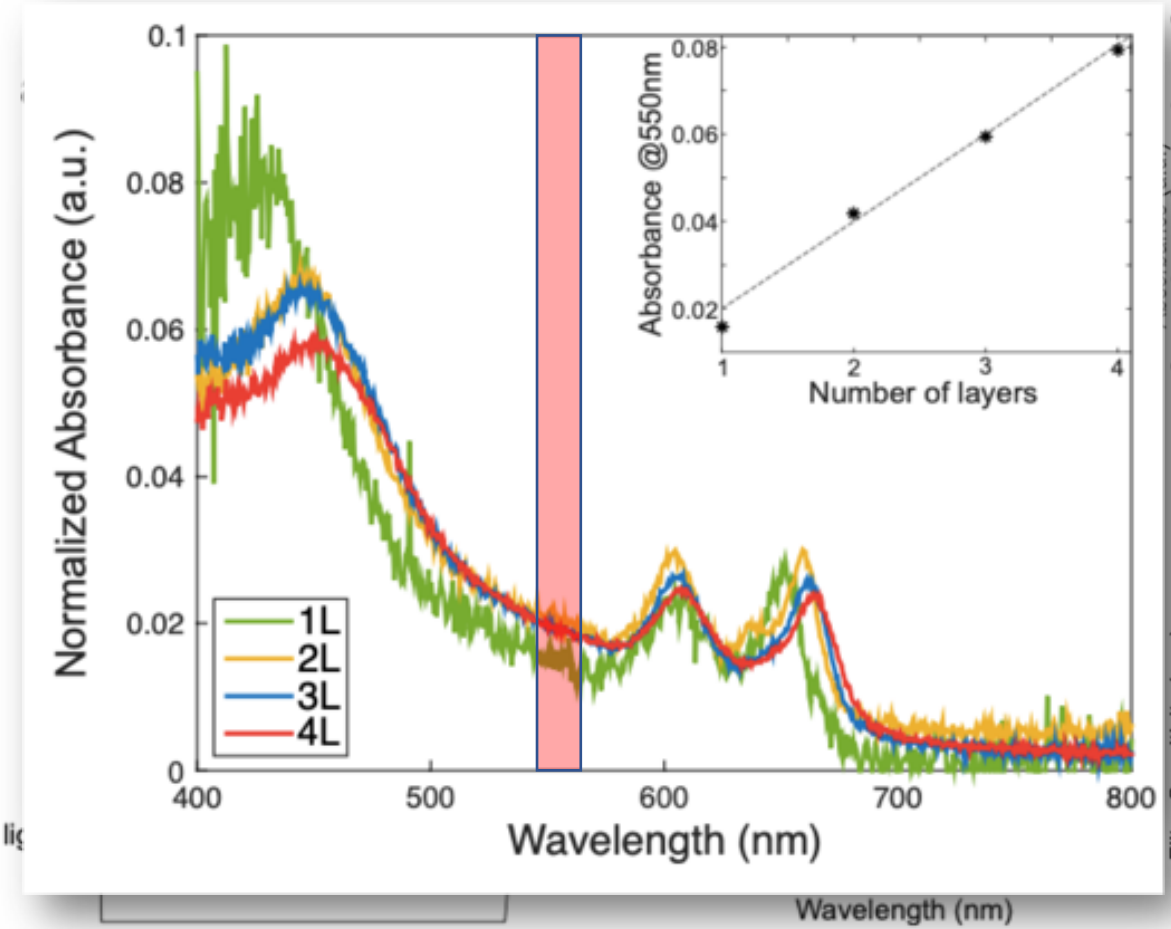

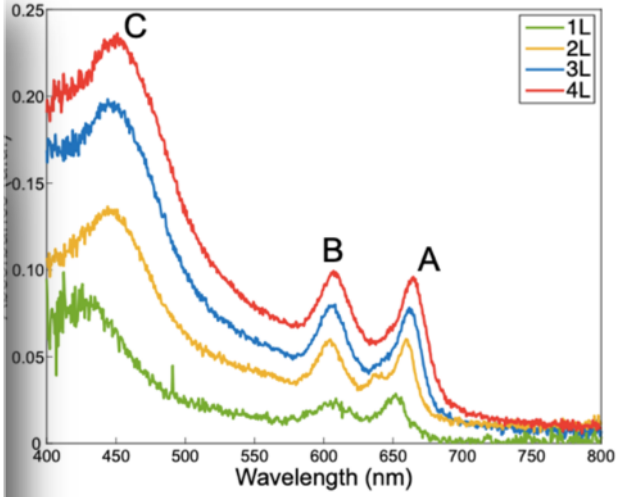

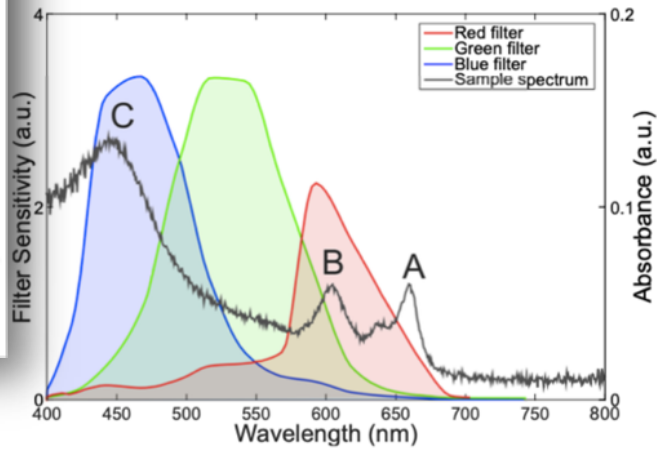

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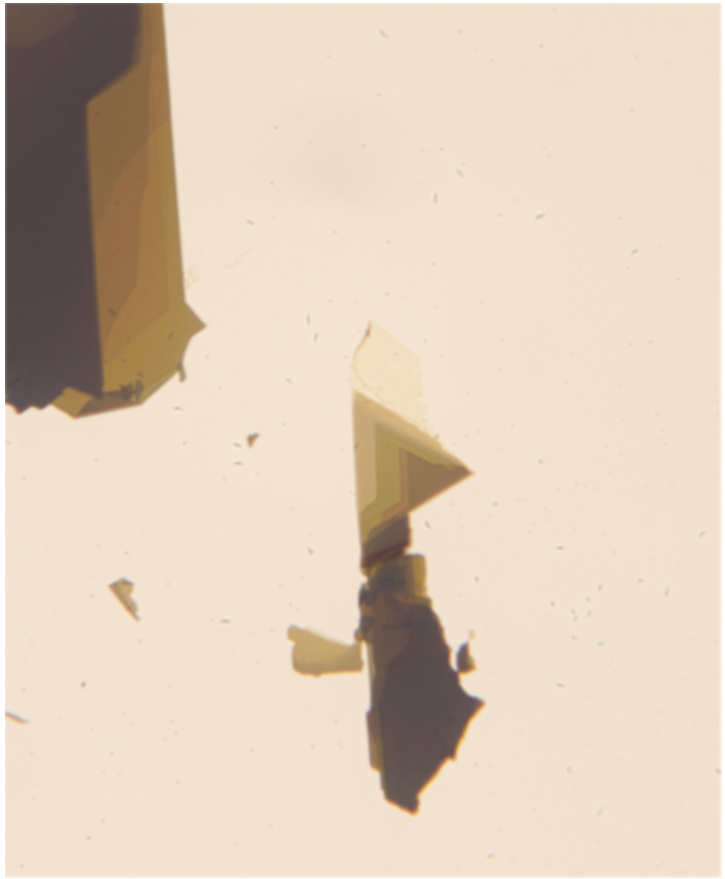

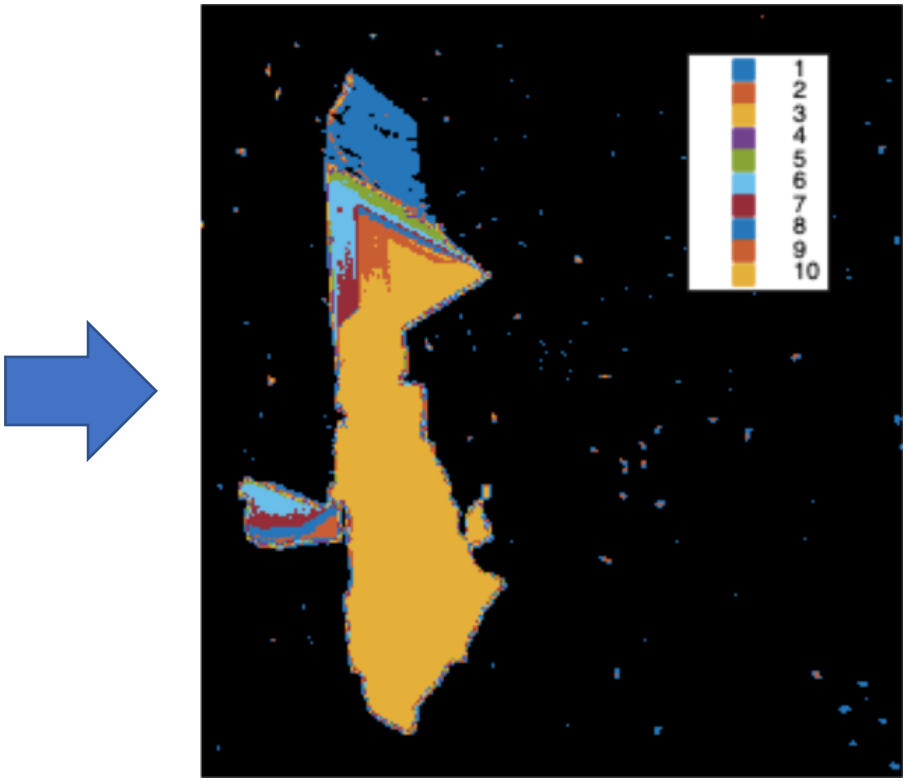

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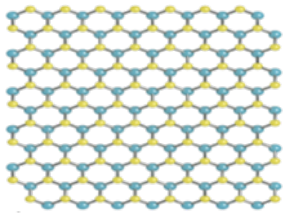

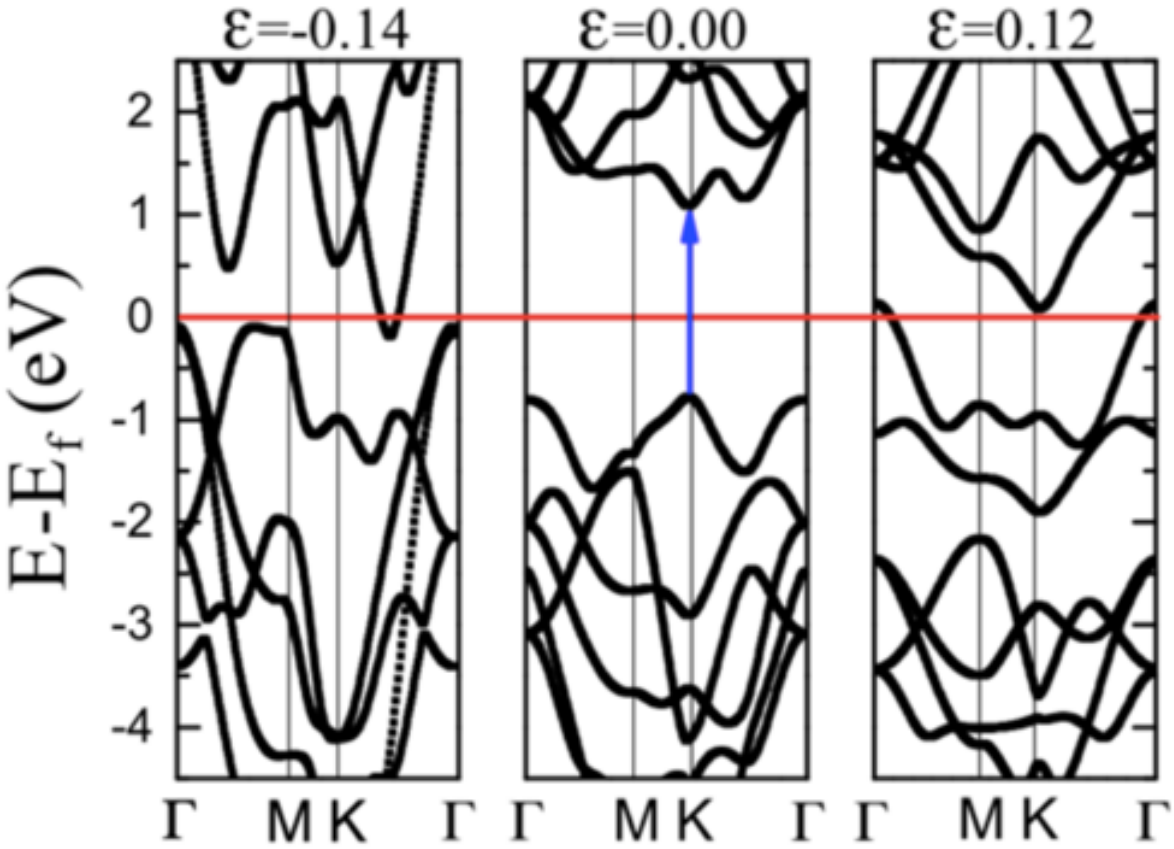

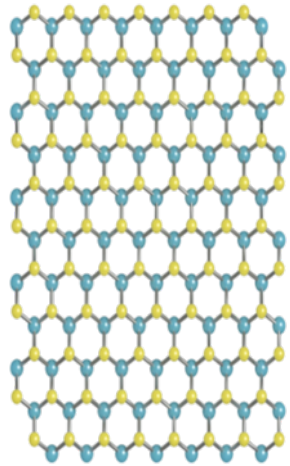

López-Suárez, Miquel, Igor Neri, and Riccardo Rurali. "Band gap engineering of MoS2 upon compression." Journal of Applied Physics 119.16 (2016): 165105.

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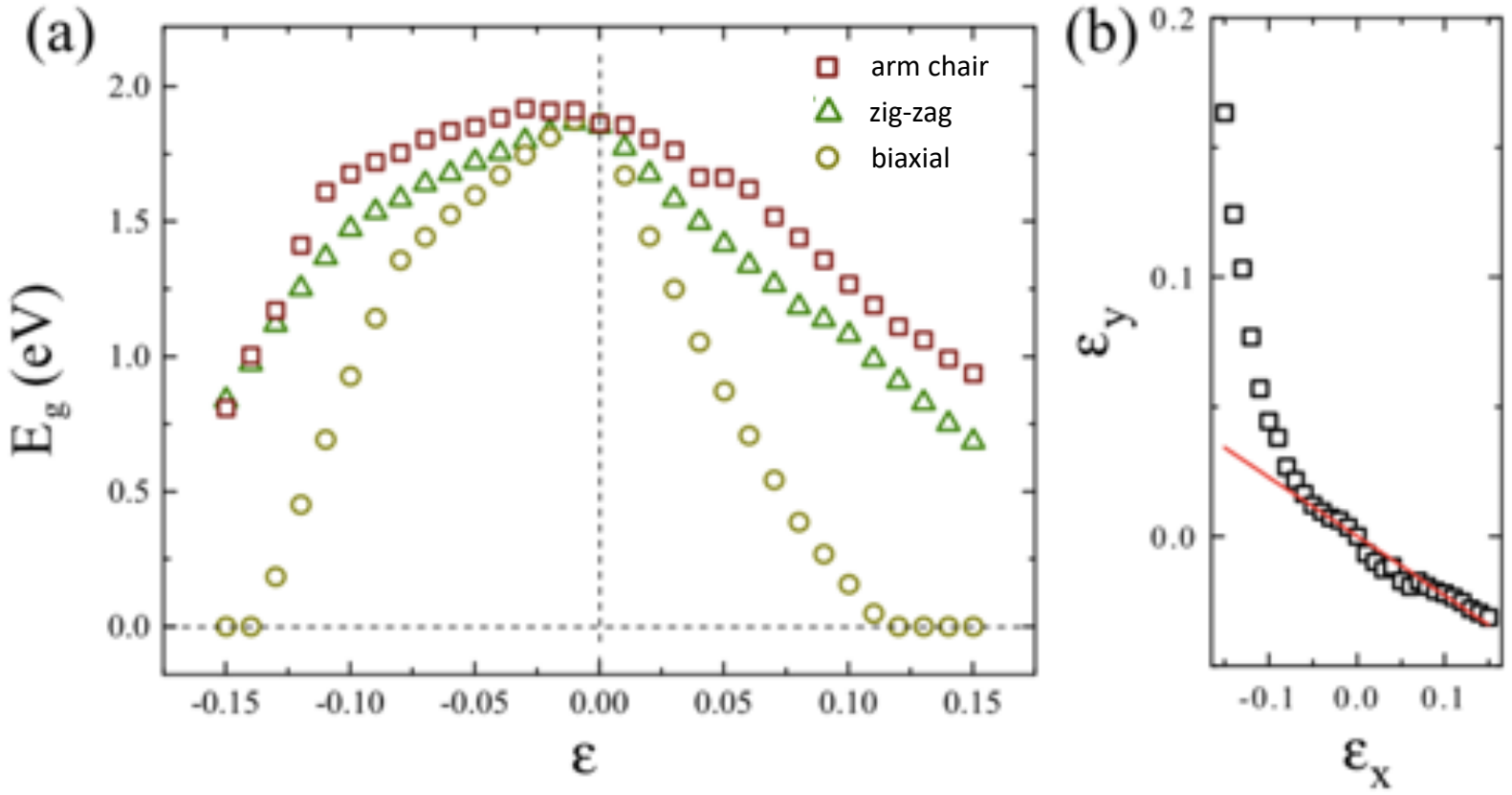

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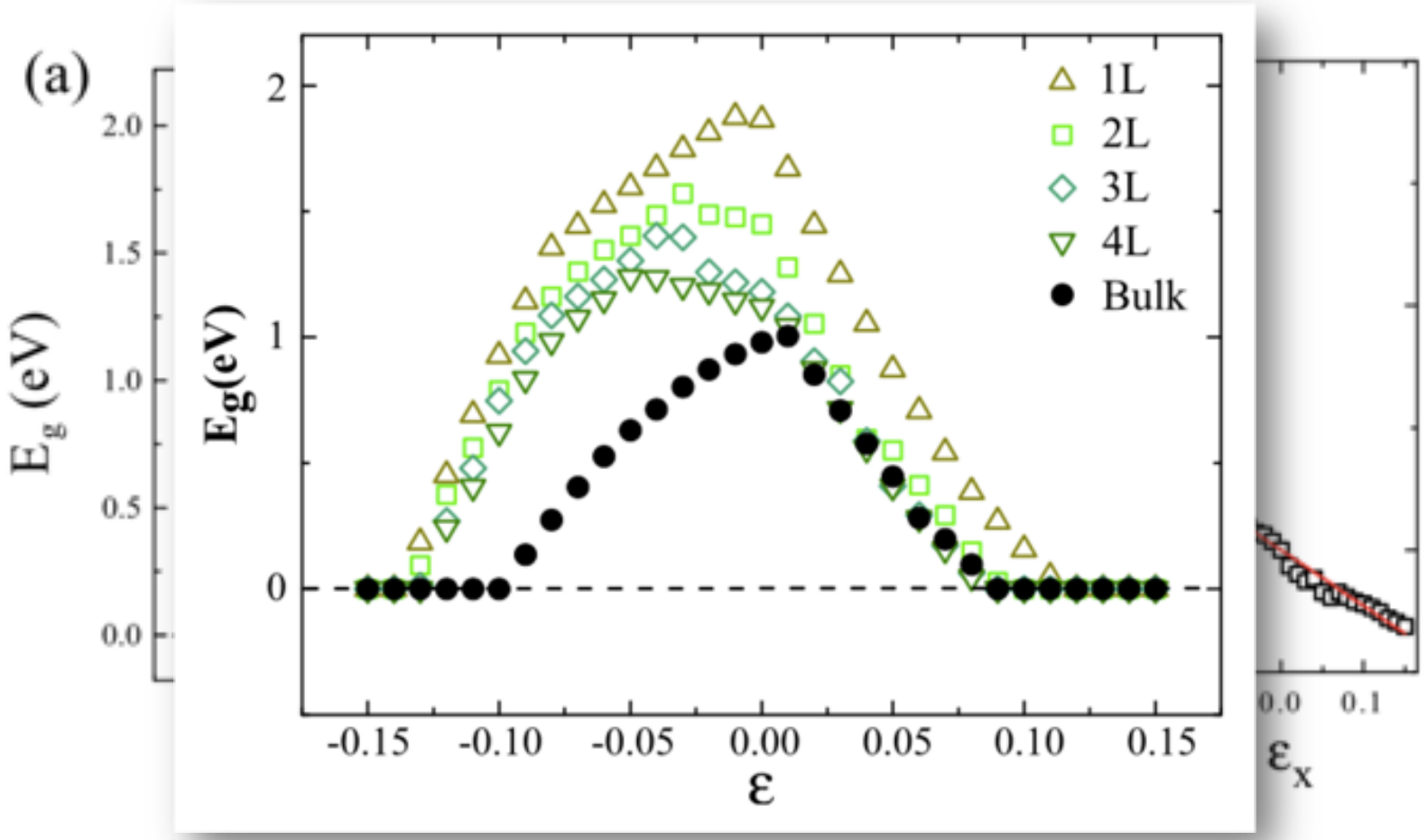

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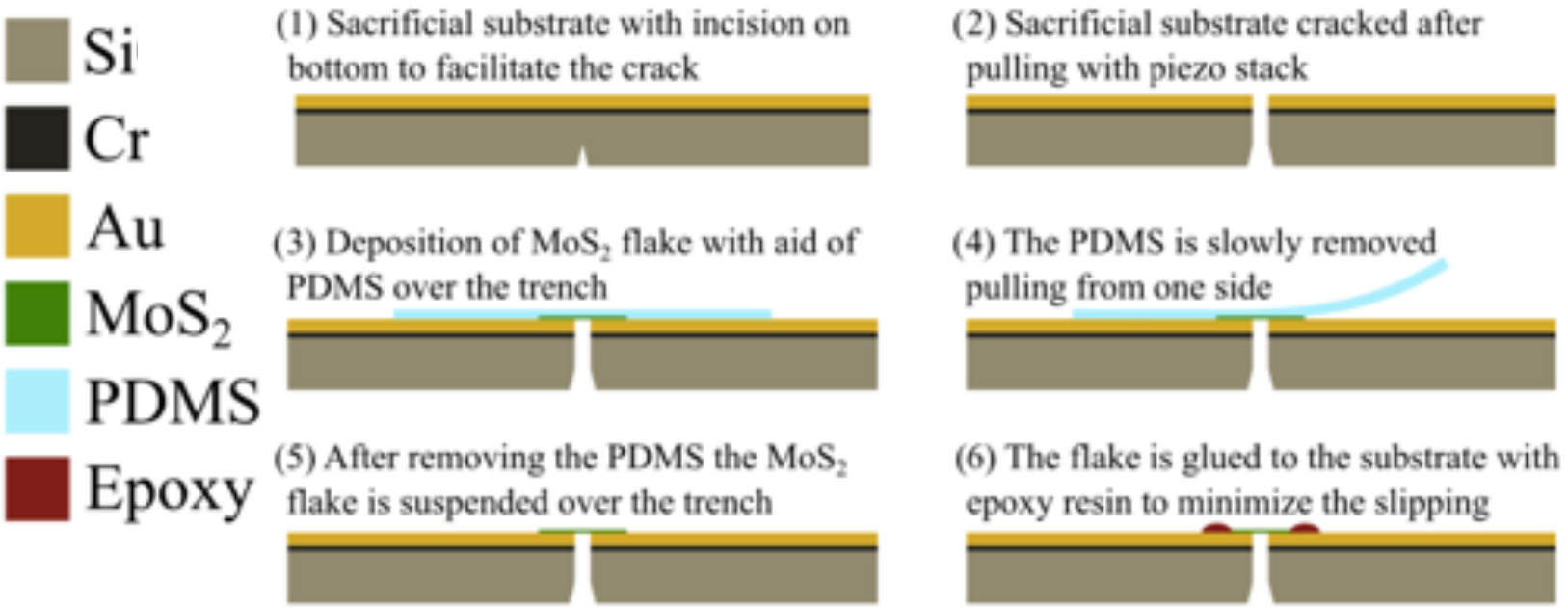
Electronic transport modulation on few-layer MoS_2 under strain



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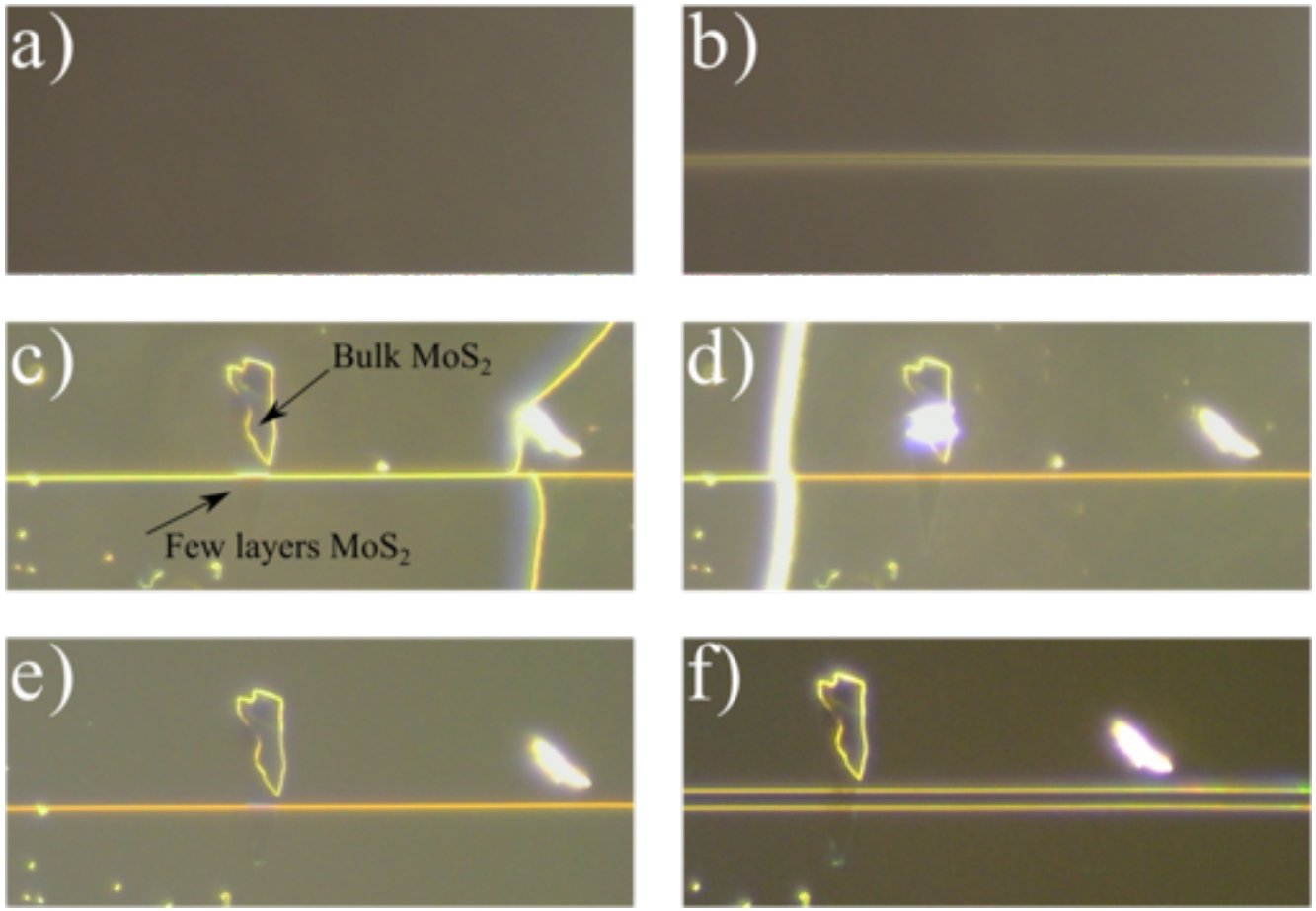

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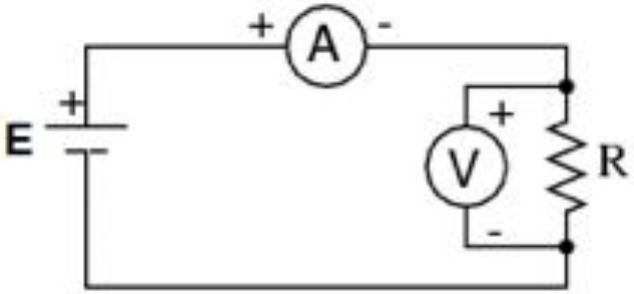

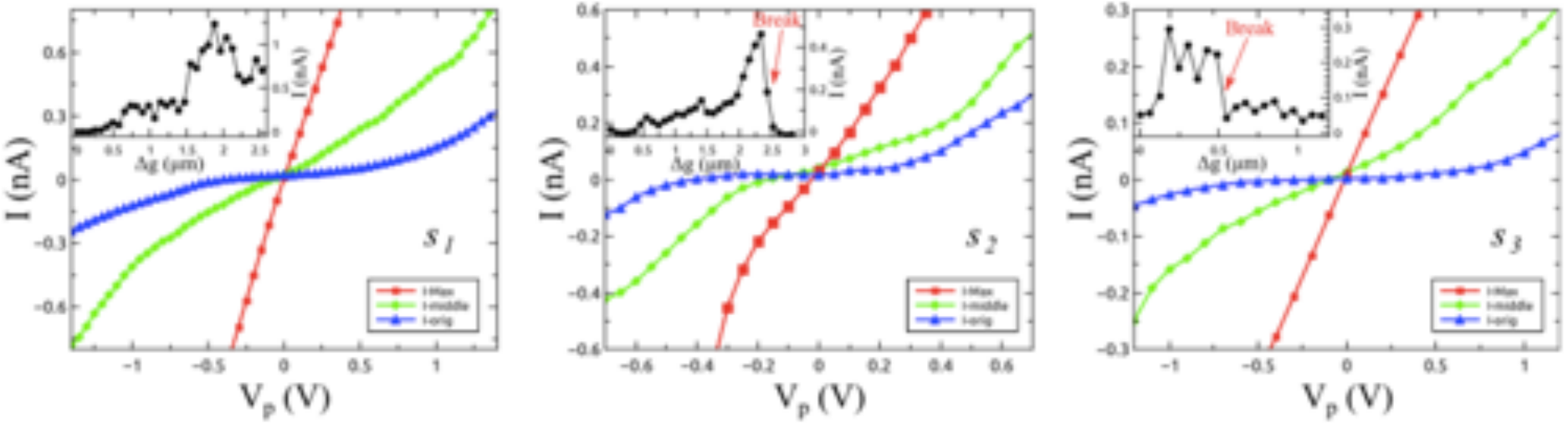

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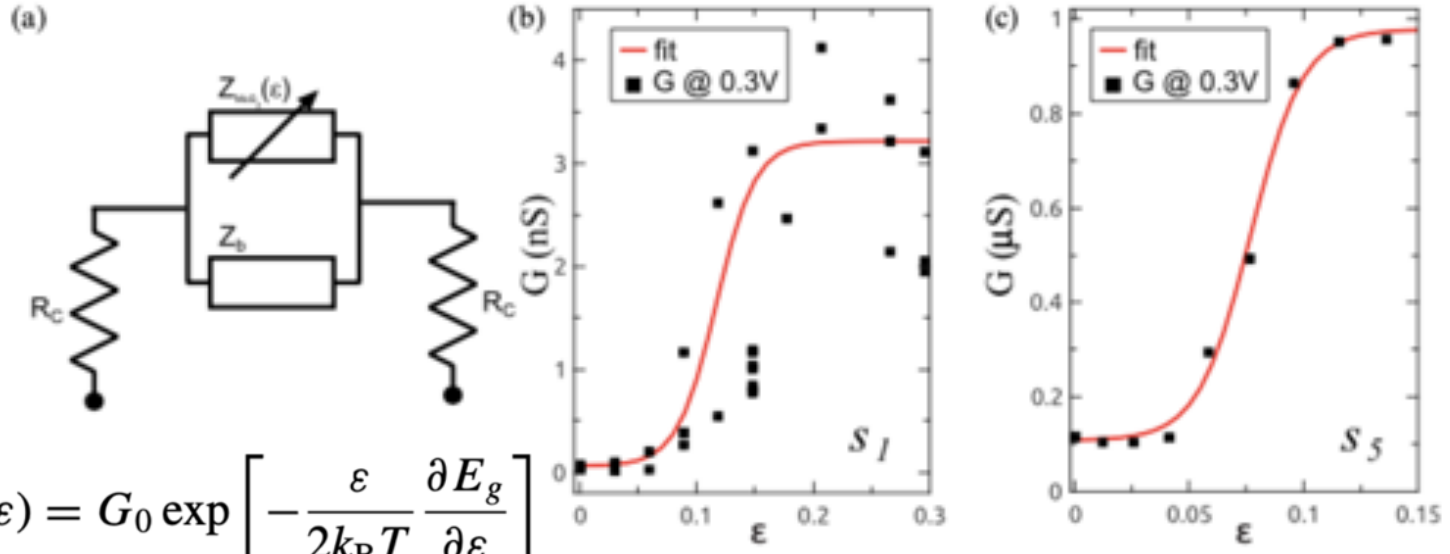

$$G_{MoS_2}(\varepsilon) = G_0 \exp\left[-\frac{\varepsilon}{2k_B T}\frac{\partial E_g}{\partial \varepsilon}\right]$$

Parameter	s_1	s_5
R_C	$310.7 \times 10^6\ \Omega$	$1.02 \times 10^6\ \Omega$
Z_b	$1.67 \times 10^{10}\ \Omega$	$8.24 \times 10^6\ \Omega$
G_0	2.94×10^{-12} S	13.05×10^{-10} S
$\partial E_g/\partial \varepsilon$	−31 meV/% strain	−45 meV/% strain

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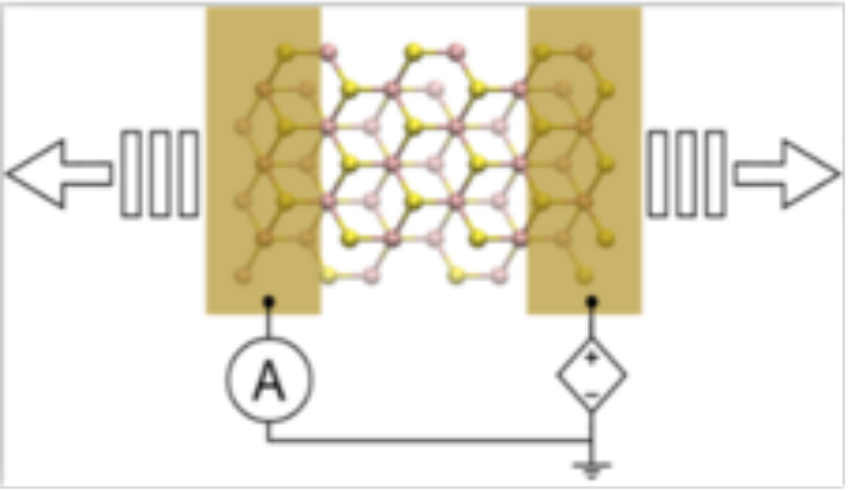
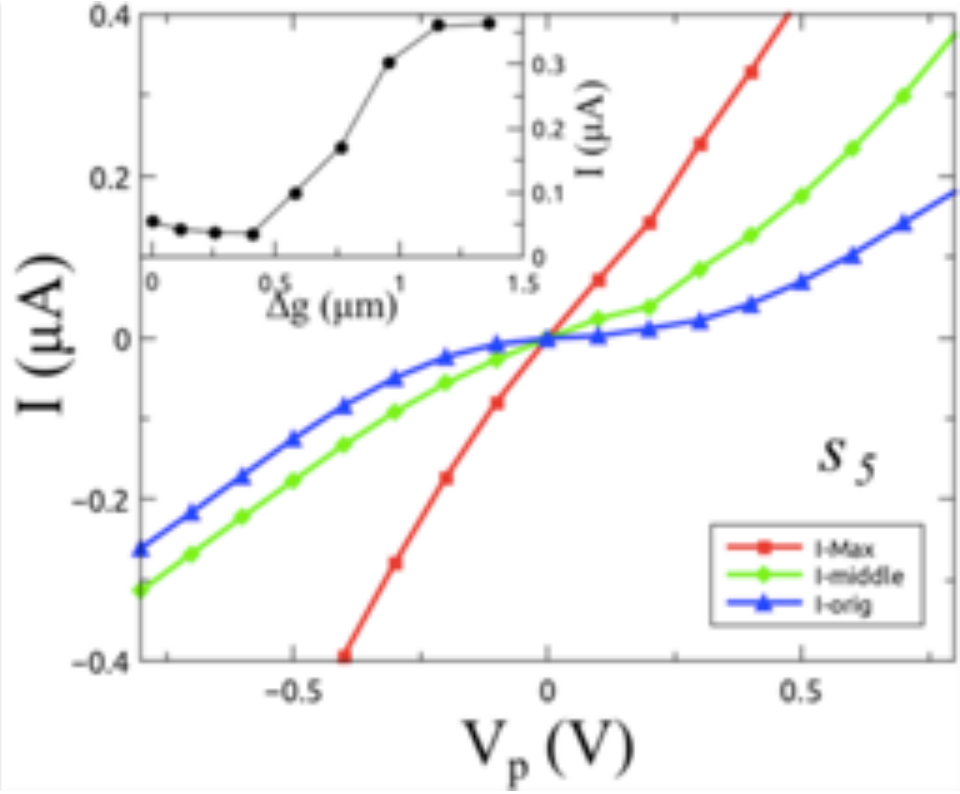
Tunable MoS_2 strain sensor

Tunable MoS_2 strain sensor





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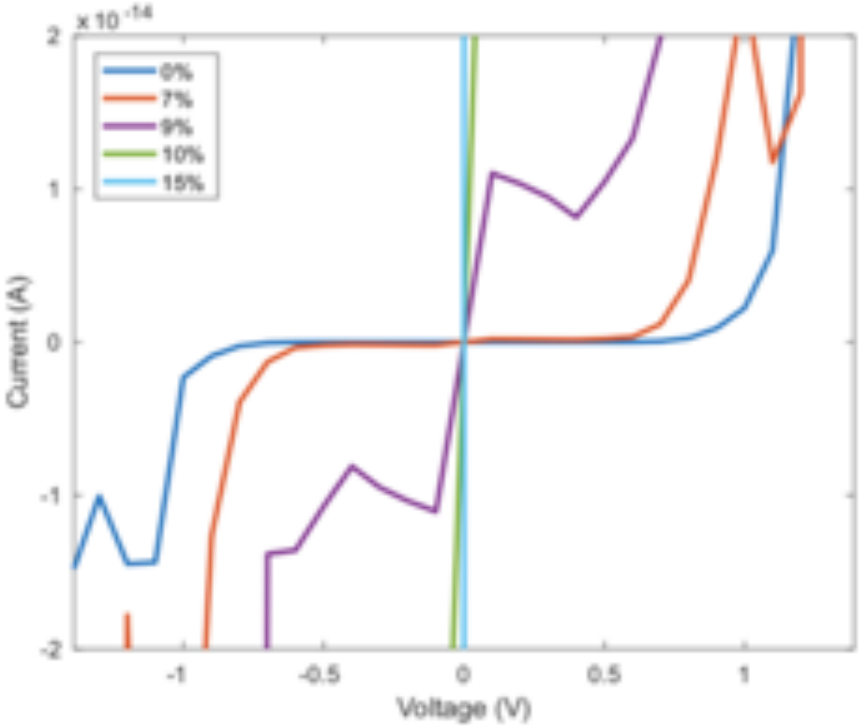
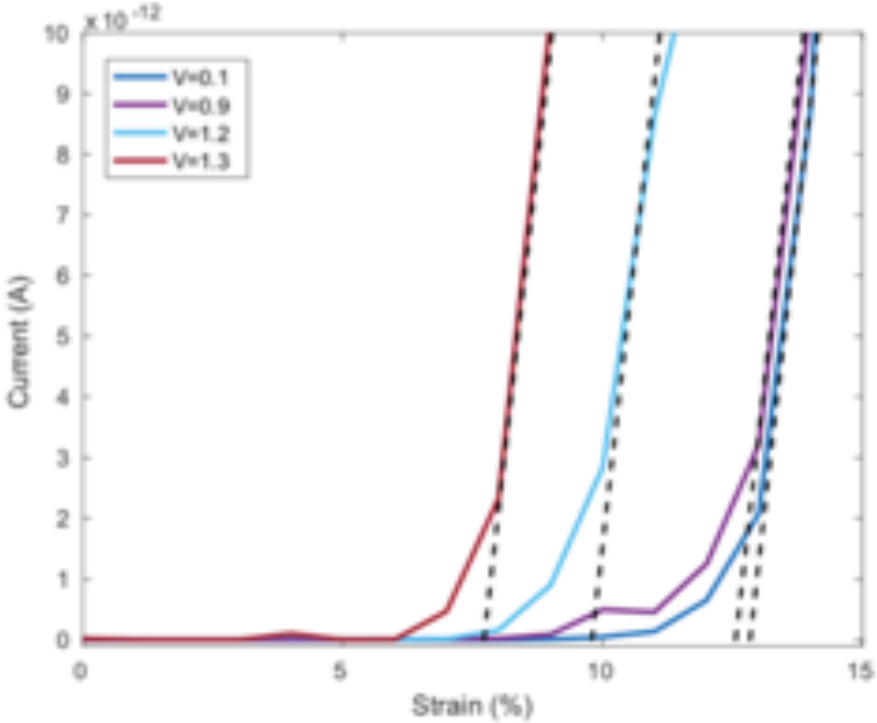
Tunable MoS_2 strain sensor





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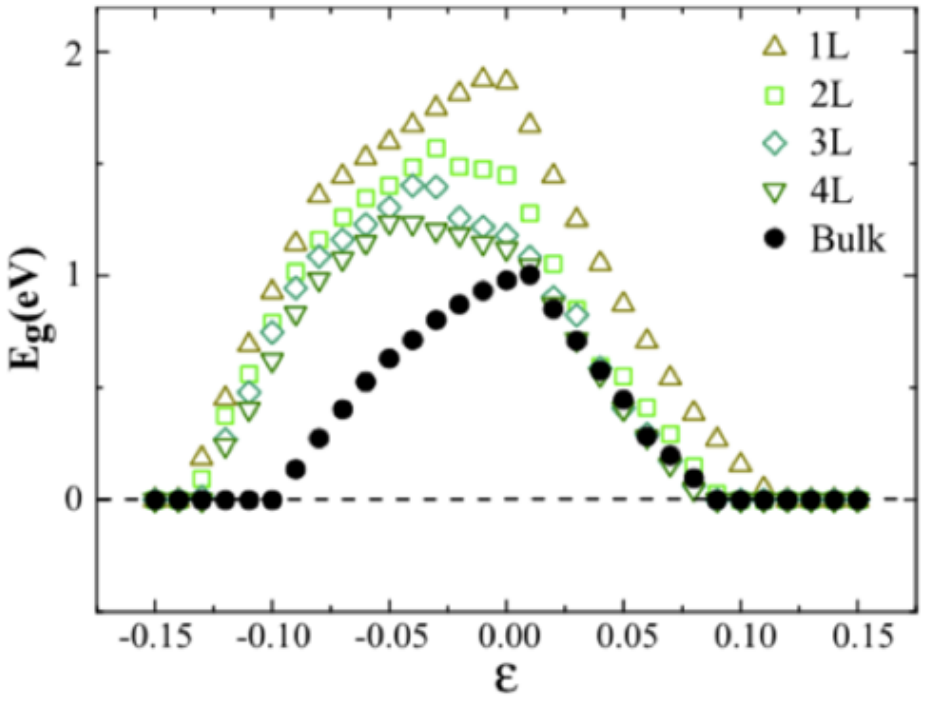
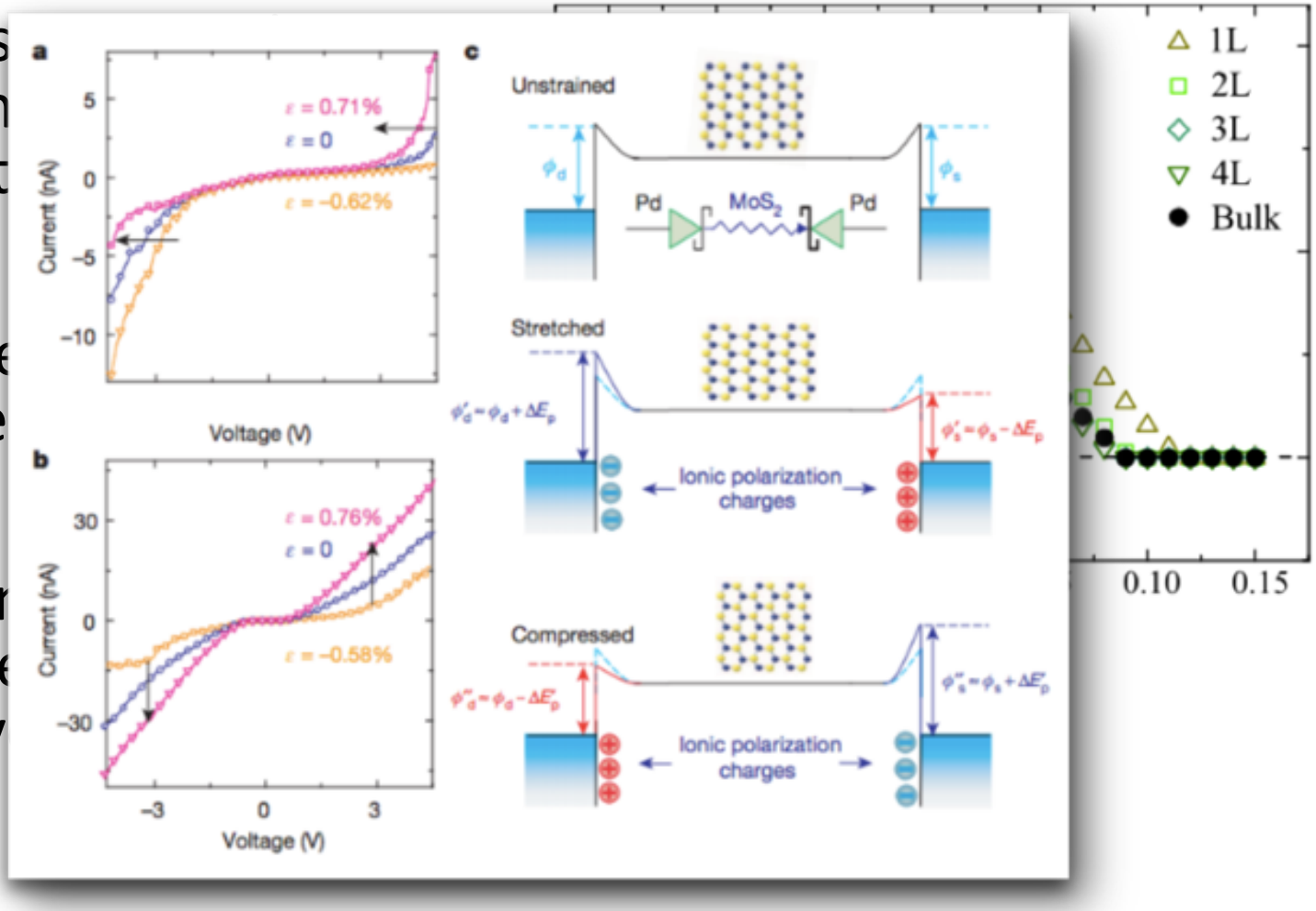
Tunable MoS_2 strain sensor

- Sensors require direct relation between two properties
- Not direct relation between Eg and strain
- Solution: exploit piezoelectricity (only odd-layered)



Tunable MoS_2 strain sensor

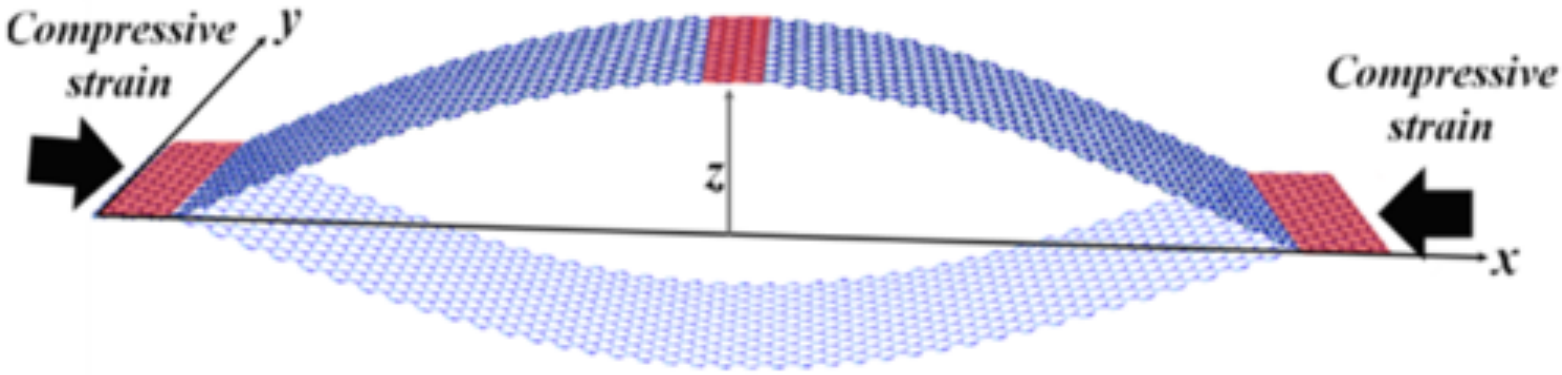
- Sensors
  relation
  propert
- Not dire
  betwee
- Solutior
  piezoele
  odd-lay



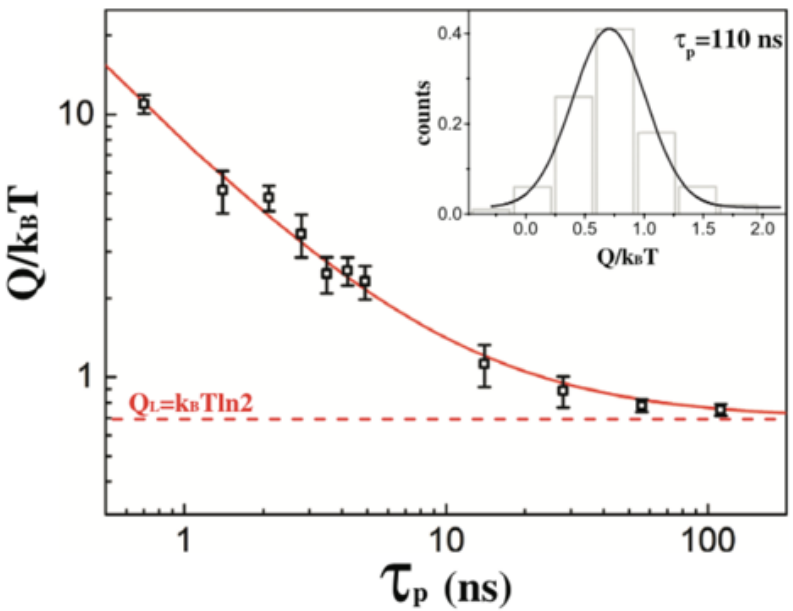
NEMS memory device

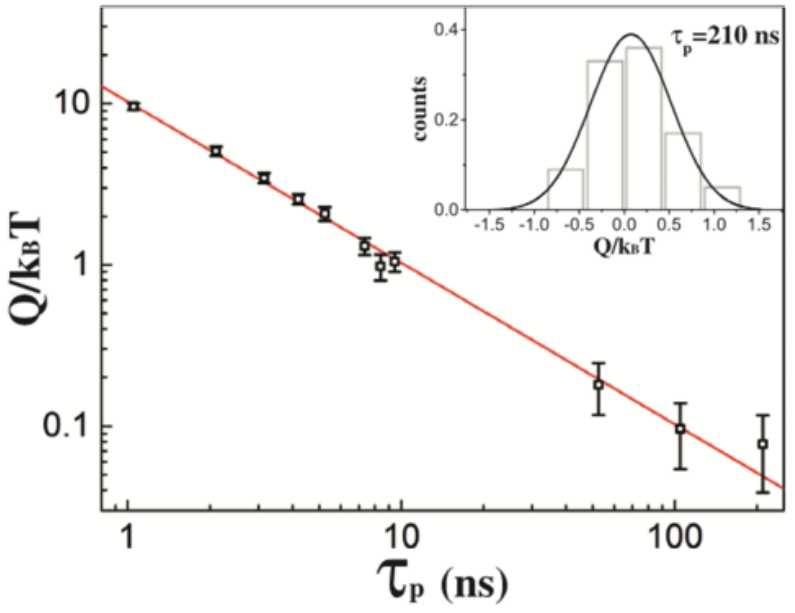
NEMS memory device

Bit 1



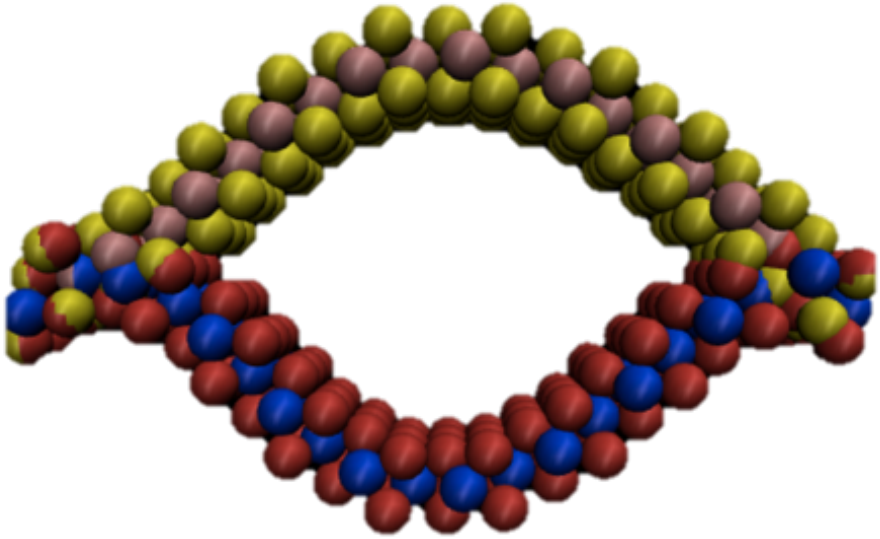
Bit 0

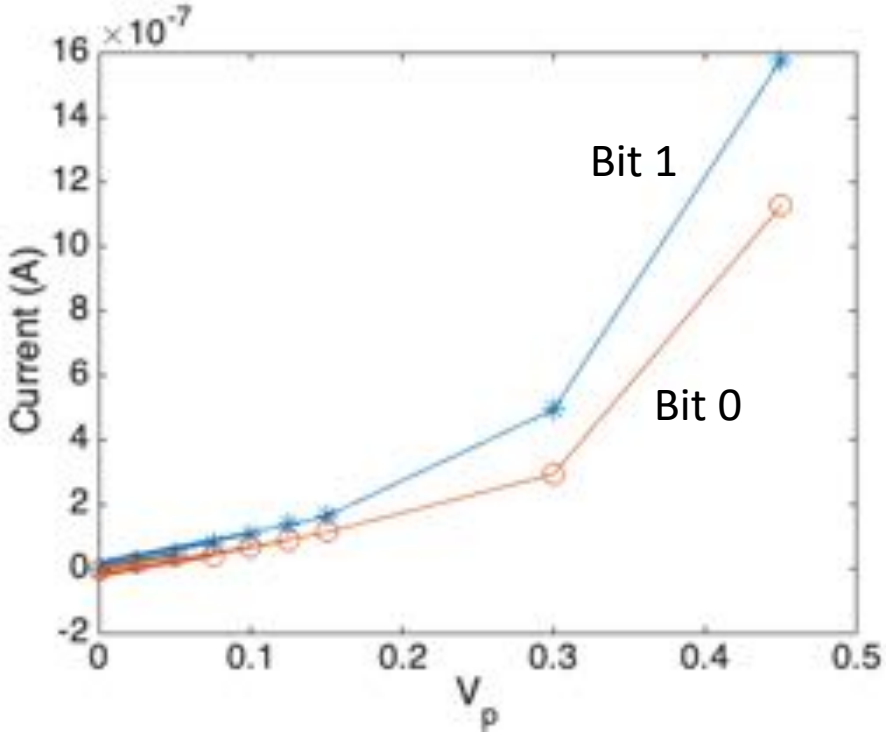




NEMS memory device

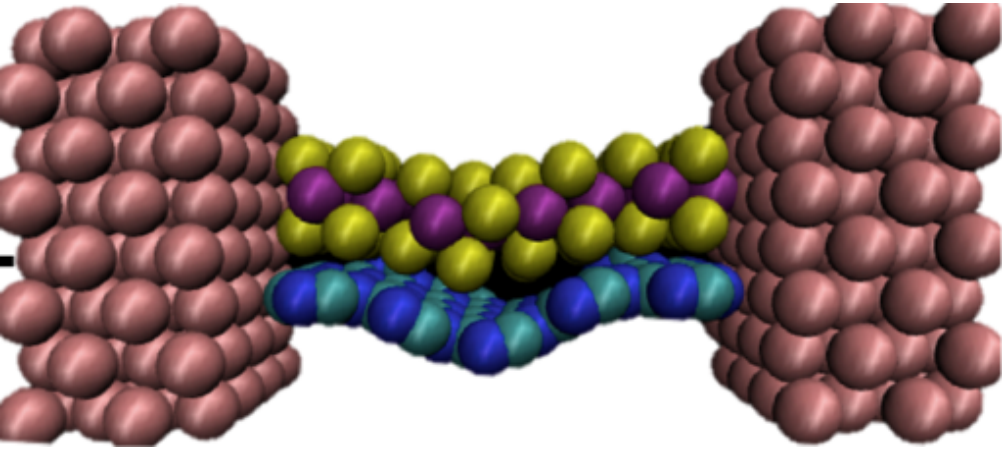
- Asymmetry in the out of plane direction
  - Engineer local strain by asymmetries on clamping

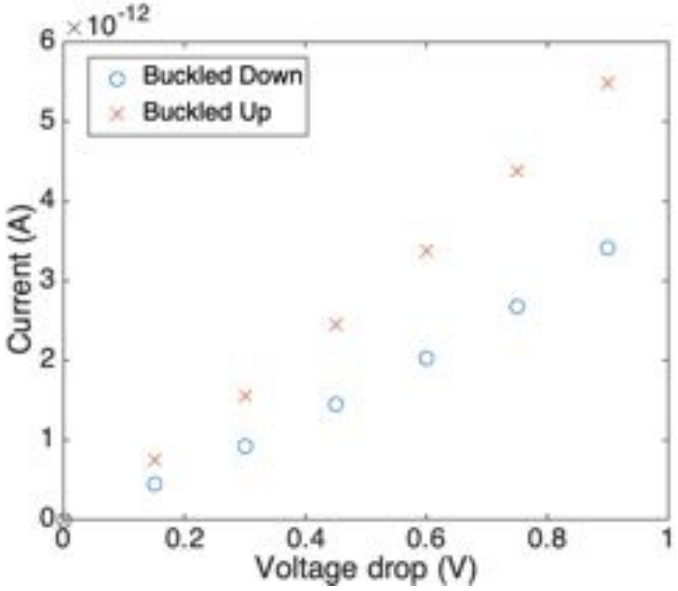




NEMS memory device

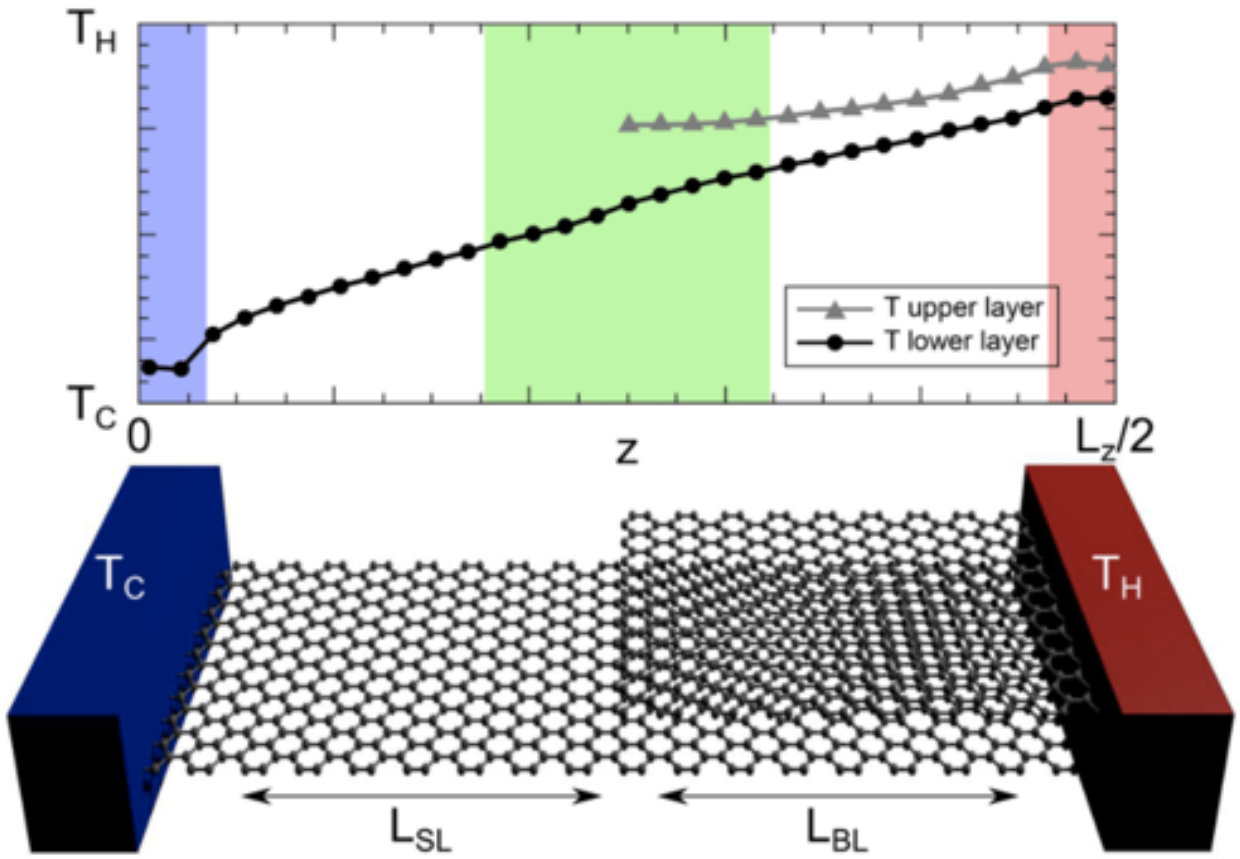
- Heterostructure
  - Piezoresistive and non-piezoresistive materials





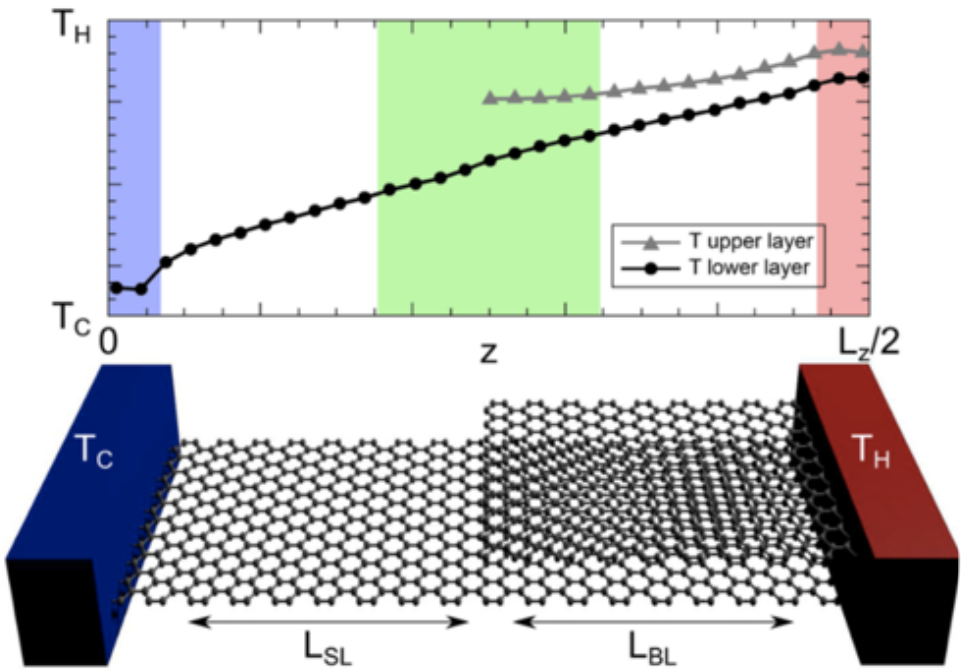
Heat rectifier

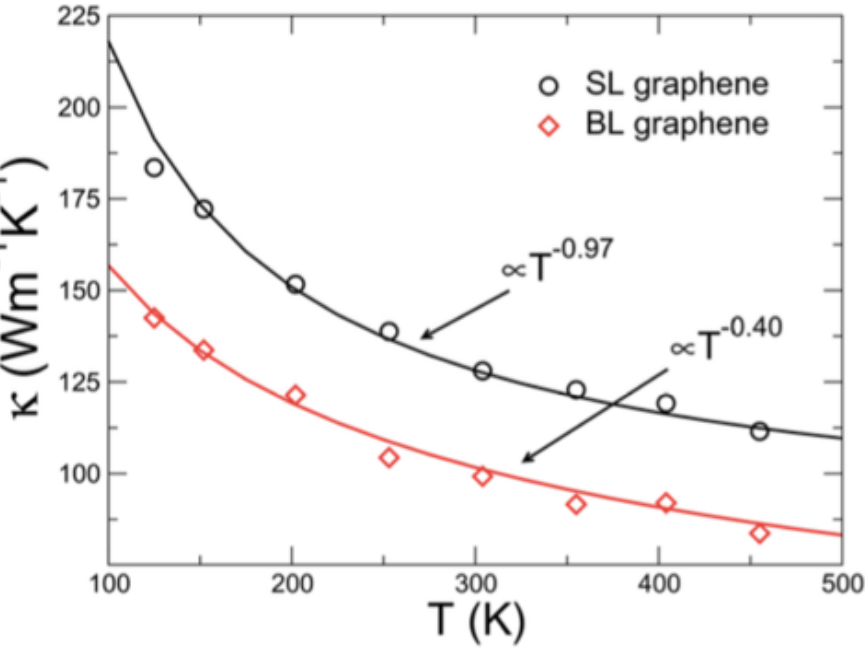
Heat rectifier



López-Suárez, Miquel, Igor Neri, and Riccardo Rurali. "Interface driven thermal rectification in a graphene–bilayer graphene junction from nonequilibrium molecular dynamics." Journal of Applied Physics 124.22 (2018): 224301.

Heat rectifier





For bulk

$$\gamma_{\max} \simeq \frac{(n_1 - n_2)}{4} \frac{\Delta T}{T_0}$$

negative

Expected $\gamma_{\max}$ ~5% for T=300 K and ΔT = 100K

$\gamma_{\max}$ ~20% for T=300 K and ΔT = 400K

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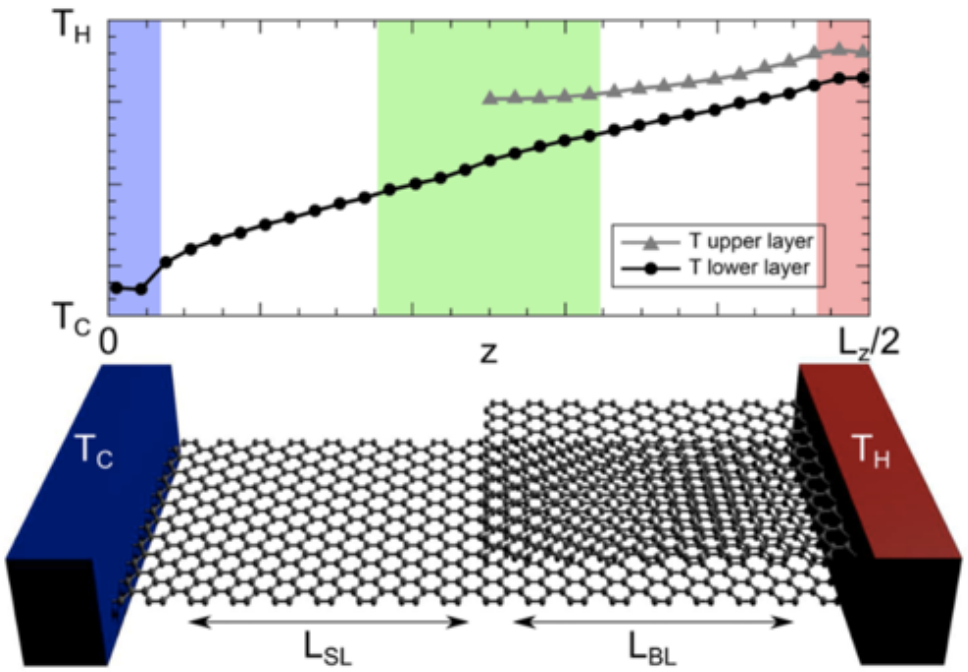
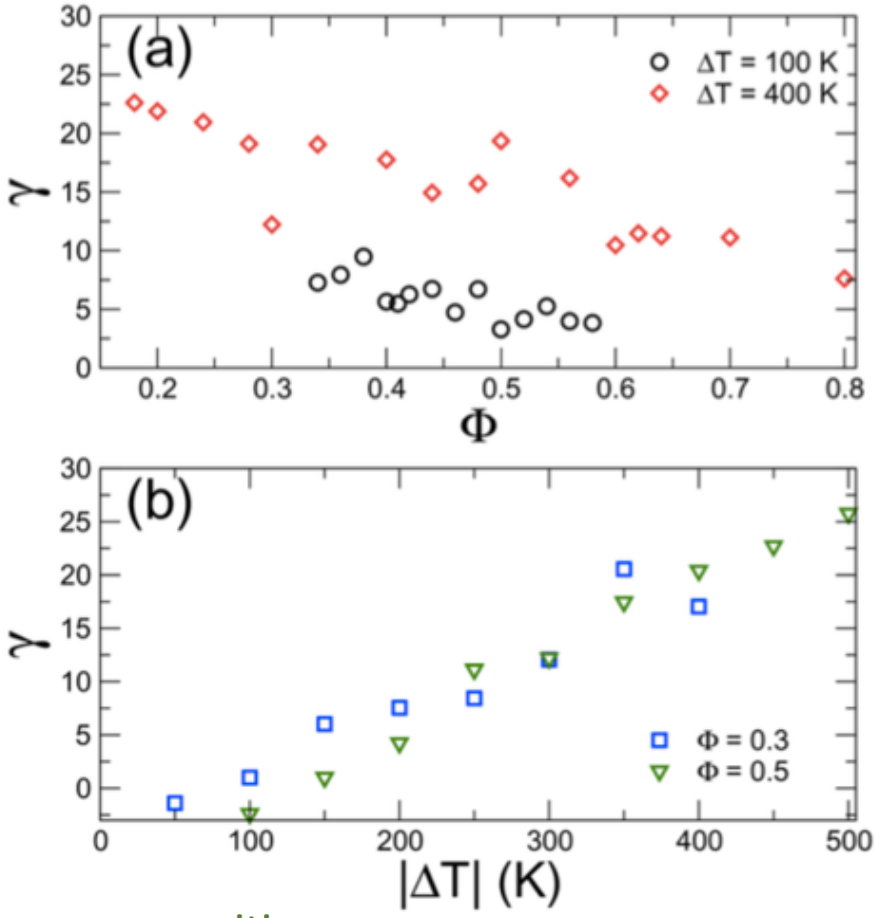
Heat rectifier

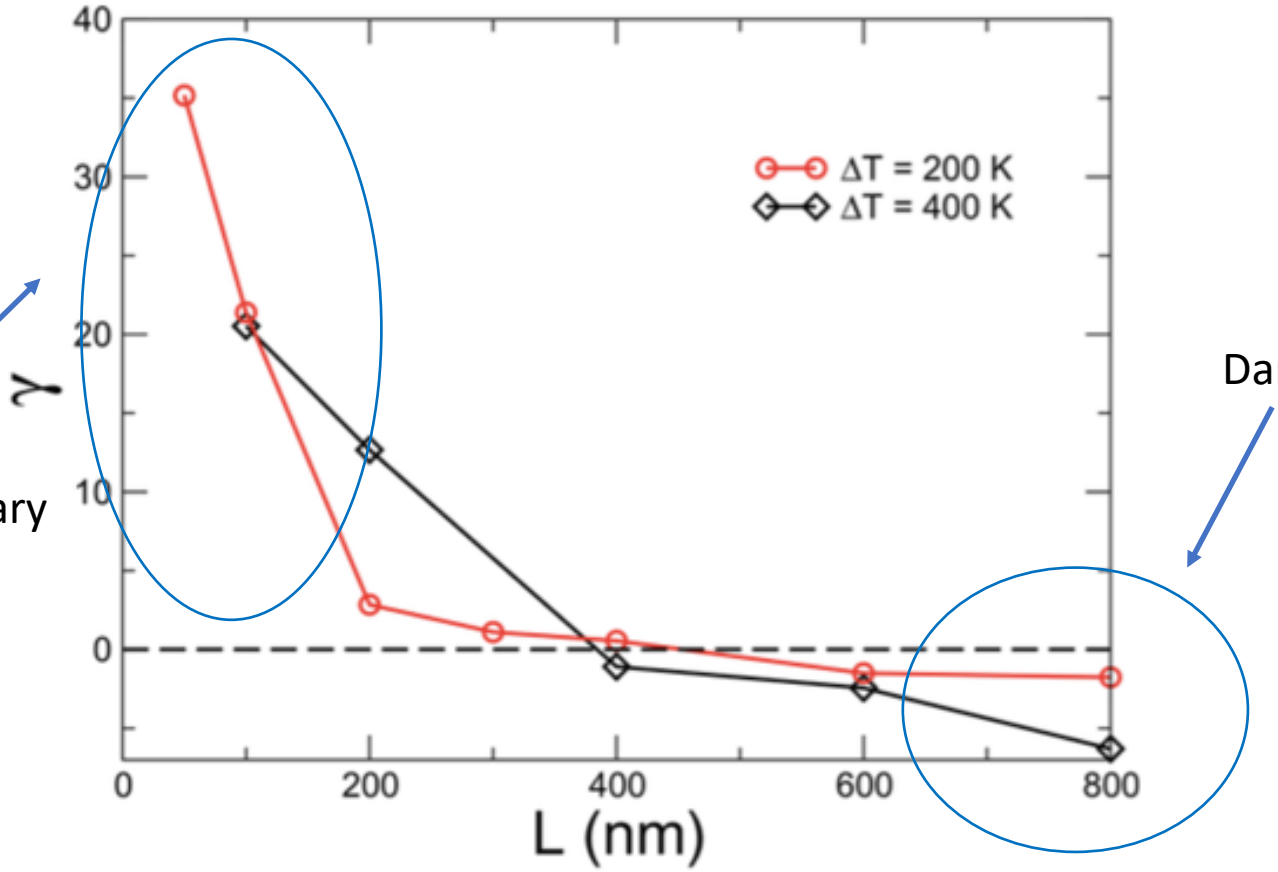




positive

López-Suárez, Miquel, Igor Neri, and Riccardo Rurali. "Interface driven thermal rectification in a graphene–bilayer graphene junction from nonequilibrium molecular dynamics." Journal of Applied Physics 124.22 (2018): 224301.

Heat rectifier



Thermal boundary resistance (TBR)

Dames' model

López-Suárez, Miquel, Igor Neri, and Riccardo Rurali. "Interface driven thermal rectification in a graphene–bilayer graphene junction from nonequilibrium molecular dynamics." Journal of Applied Physics 124.22 (2018): 224301.

Thank you for your attention