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University of Basel

Giant energy dissipation on twisted bilayer graphene at magic angle twist

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CAPRI SPRING SCHOOL

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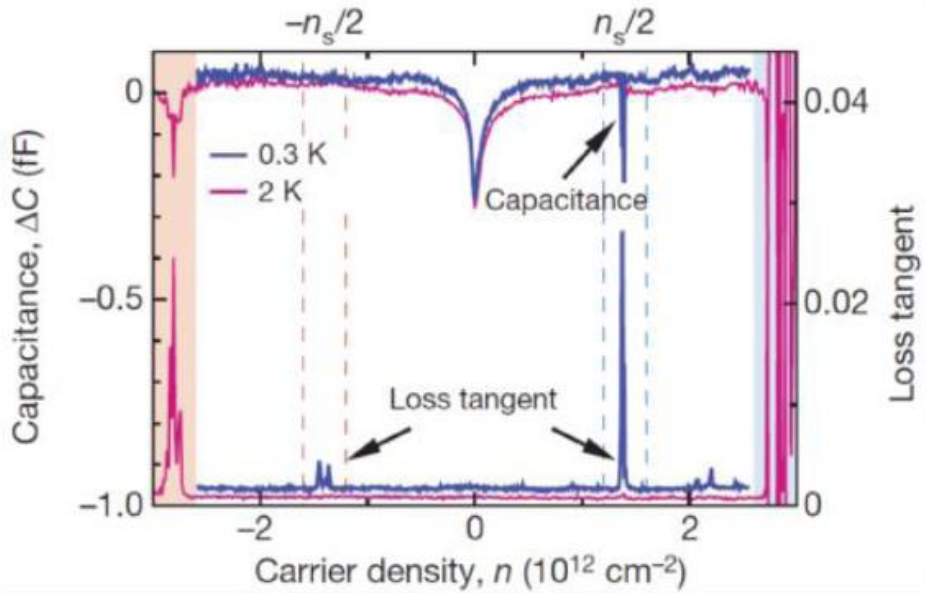
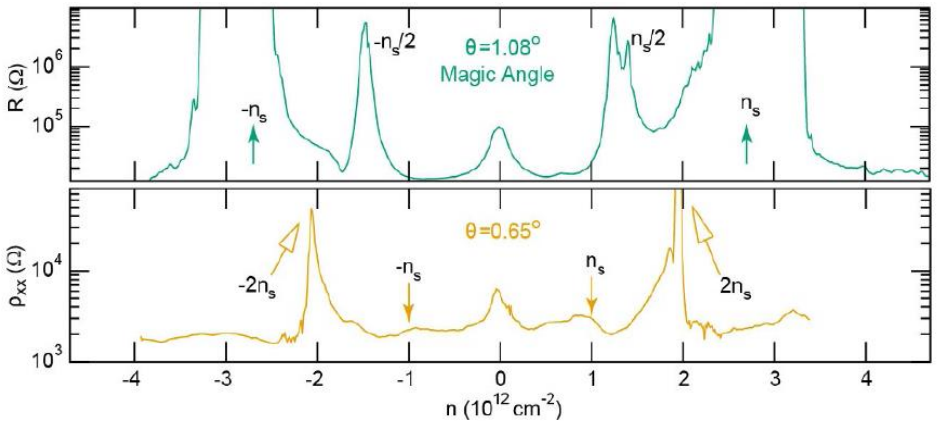
INTRODUCTION
• TBG





Capacitance measurement on twisted bilayer graphene, showing a capacitance drop at half filling (insulating state).

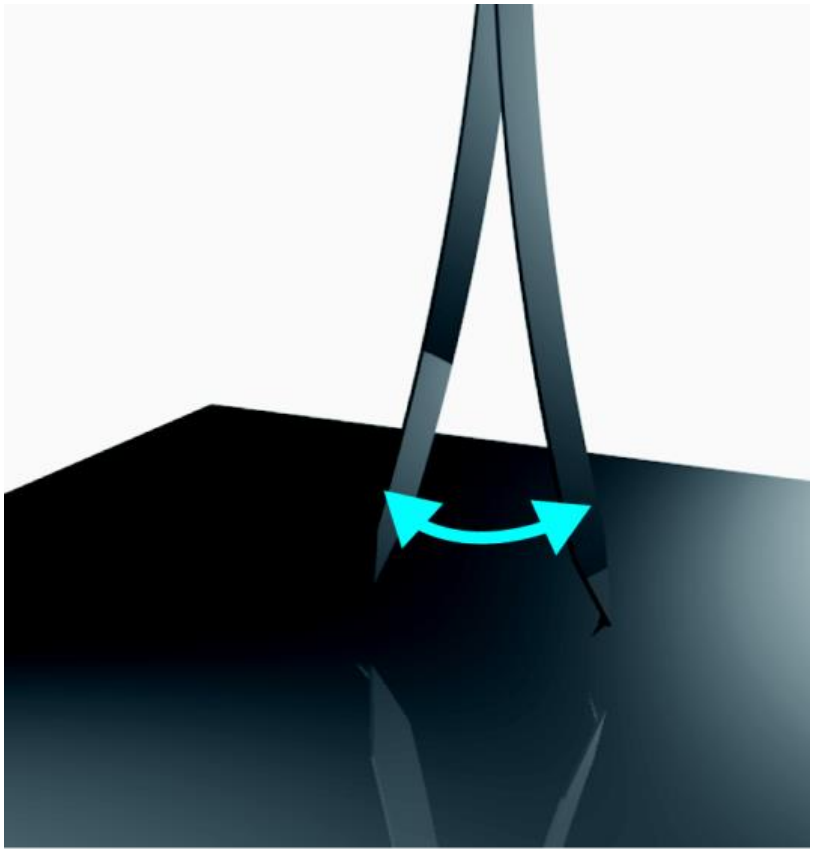
Transport measurements on TBG show peaks in resistivity at correlated insulating states. The angle dependence is strong:

$$n_s = \frac{4}{A} \approx \frac{8\theta^2}{\sqrt{3}A^2}$$

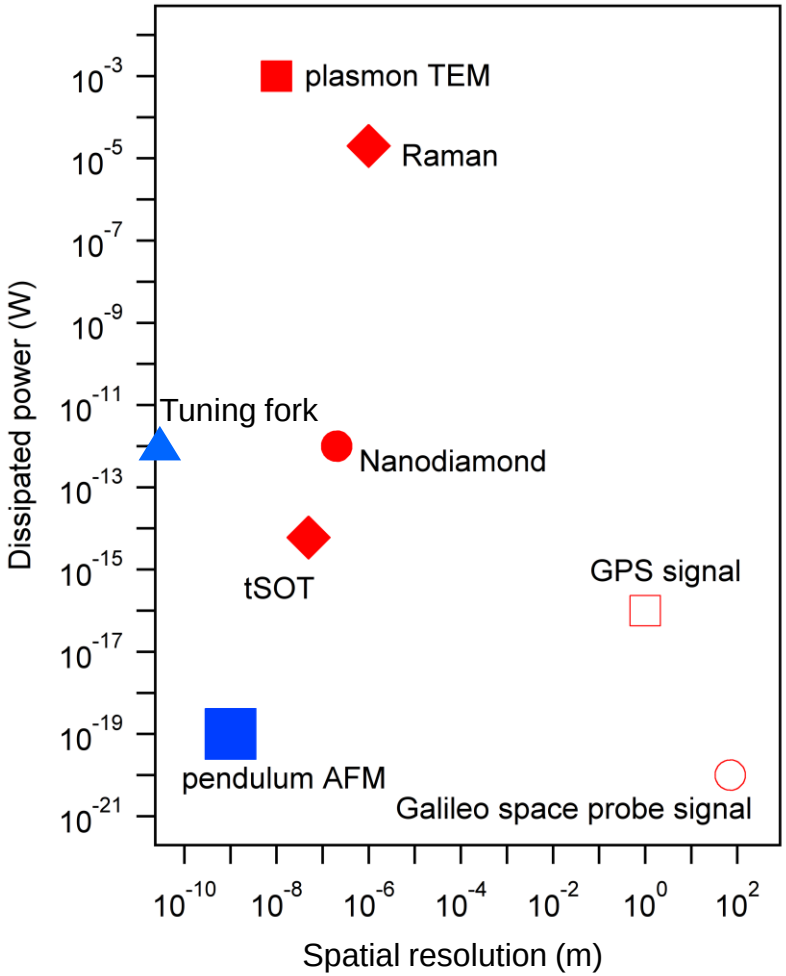
Y. Cao, et al., ***Correlated insulator behaviour at half-filling in magic-angle graphene superlattices,*** *Nature 556, 80 (2018).*

INTRODUCTION

• Pendulum AFM – p-AFM



Low stiffness: k=0.18 N/m
High quality factor: Q=500000



EXPERIMENT
• Sample

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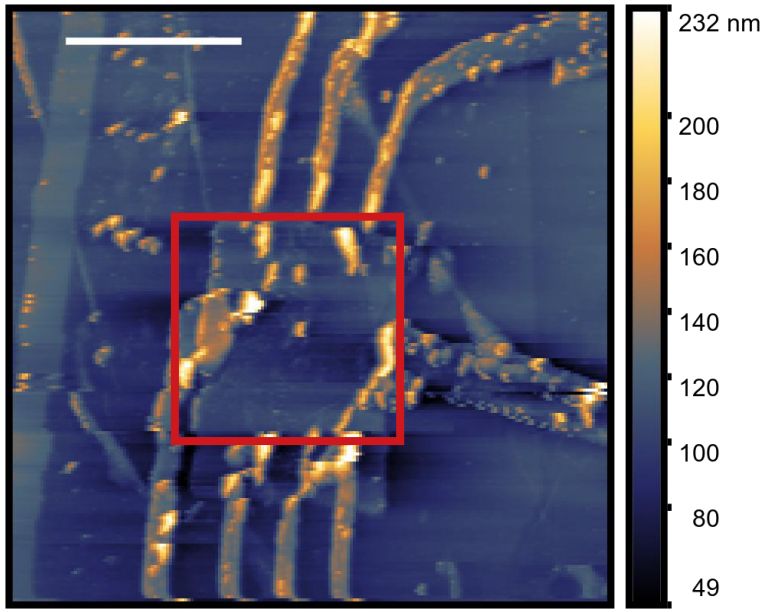
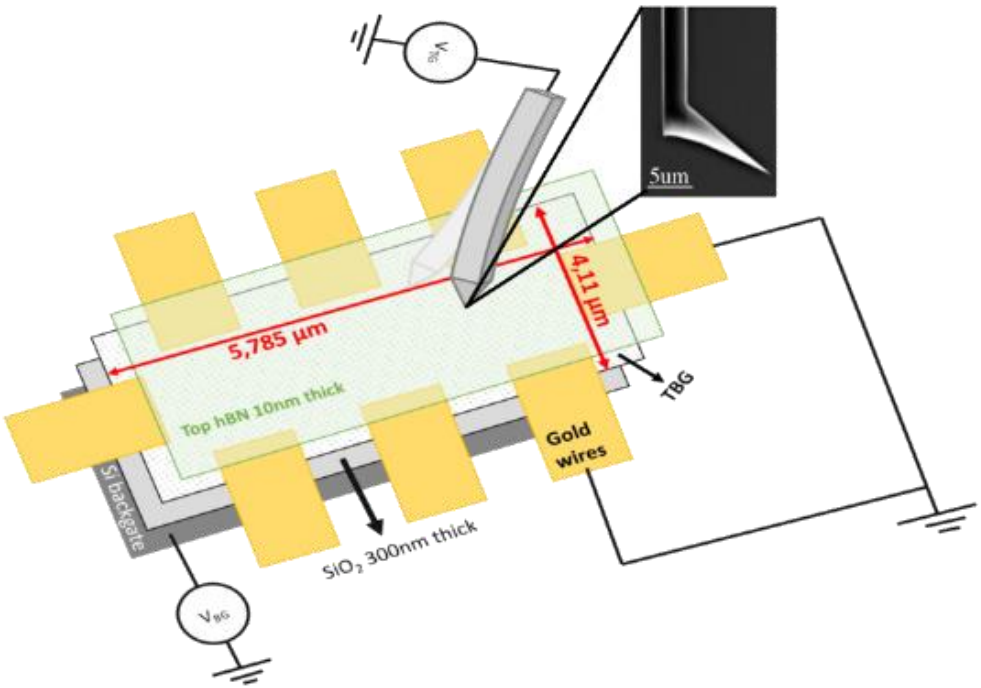
Scale bar 2um



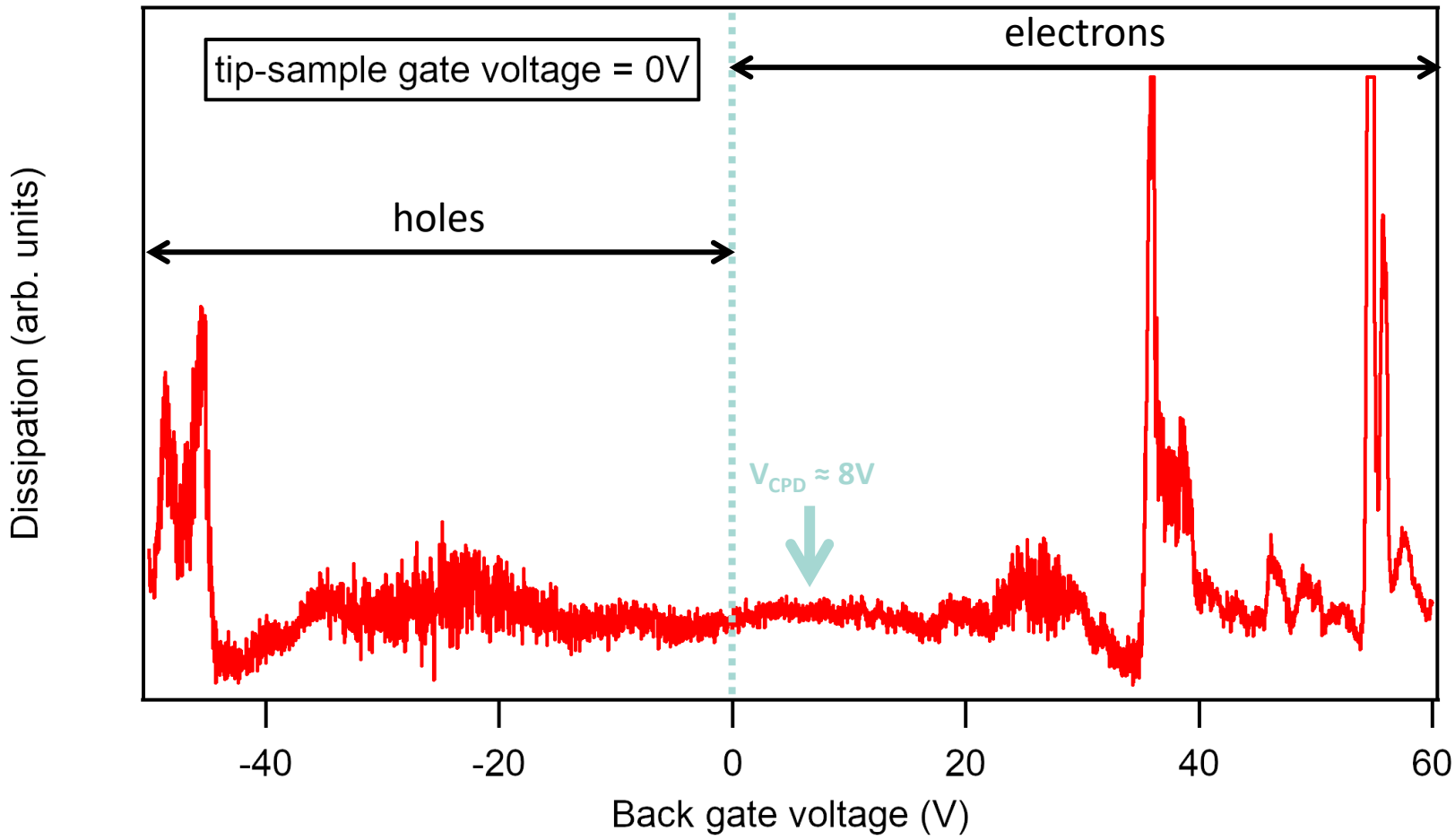
AFM image of TBG device (red rectangle) is contacted by 8 gold wires. Only two of them are connected and we kept them grounded.



Cantilever tip as an oscillating and sensing top-gate, coupled capacitively to the underlying TBG.

RESULTS

- **Energy dissipation vs Gate voltage**



d= 150 nm

RESULTS

• Back gate and doping

Back gate capacitance (C_{ox}) is equal to:

$$C_{ox} = \frac{\varepsilon_0 \varepsilon}{t_{ox}} = \frac{3.9 \times 8.854 \cdot 10^{-12}}{300nm} = 1.15 \cdot 10^{-4} F.m^{-2}$$

The doping concentration: $n = \frac{C_{ox} \times V_{BG}}{q}$

$$n = n_s \approx \frac{8\theta^2}{\sqrt{3}a^2} = 2.83 \cdot 10^{12} cm^{-2}$$

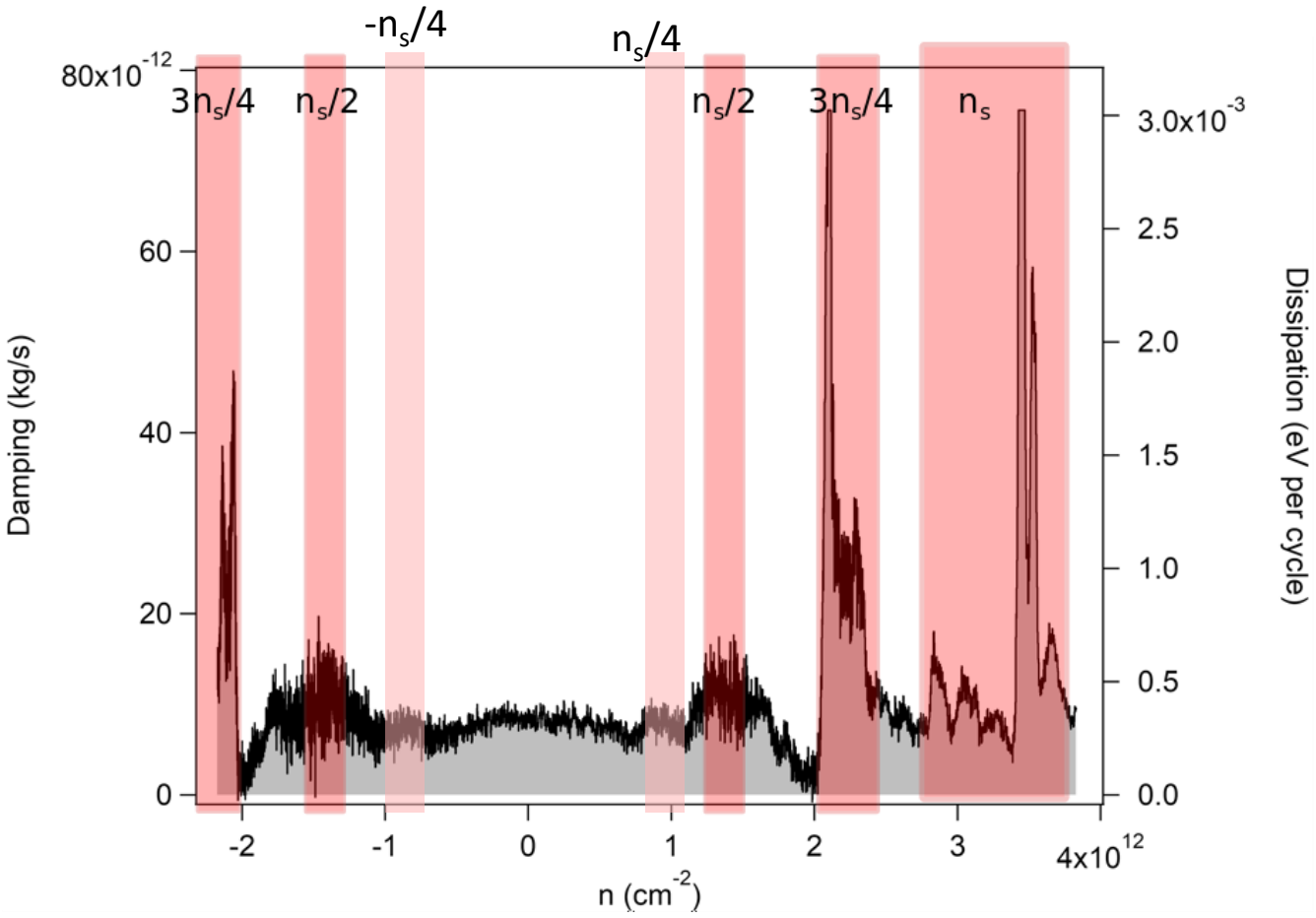
Our graphene is not exactly 1.08° twisted. The twist angle is 1.1°.

RESULTS

• Back gate and doping

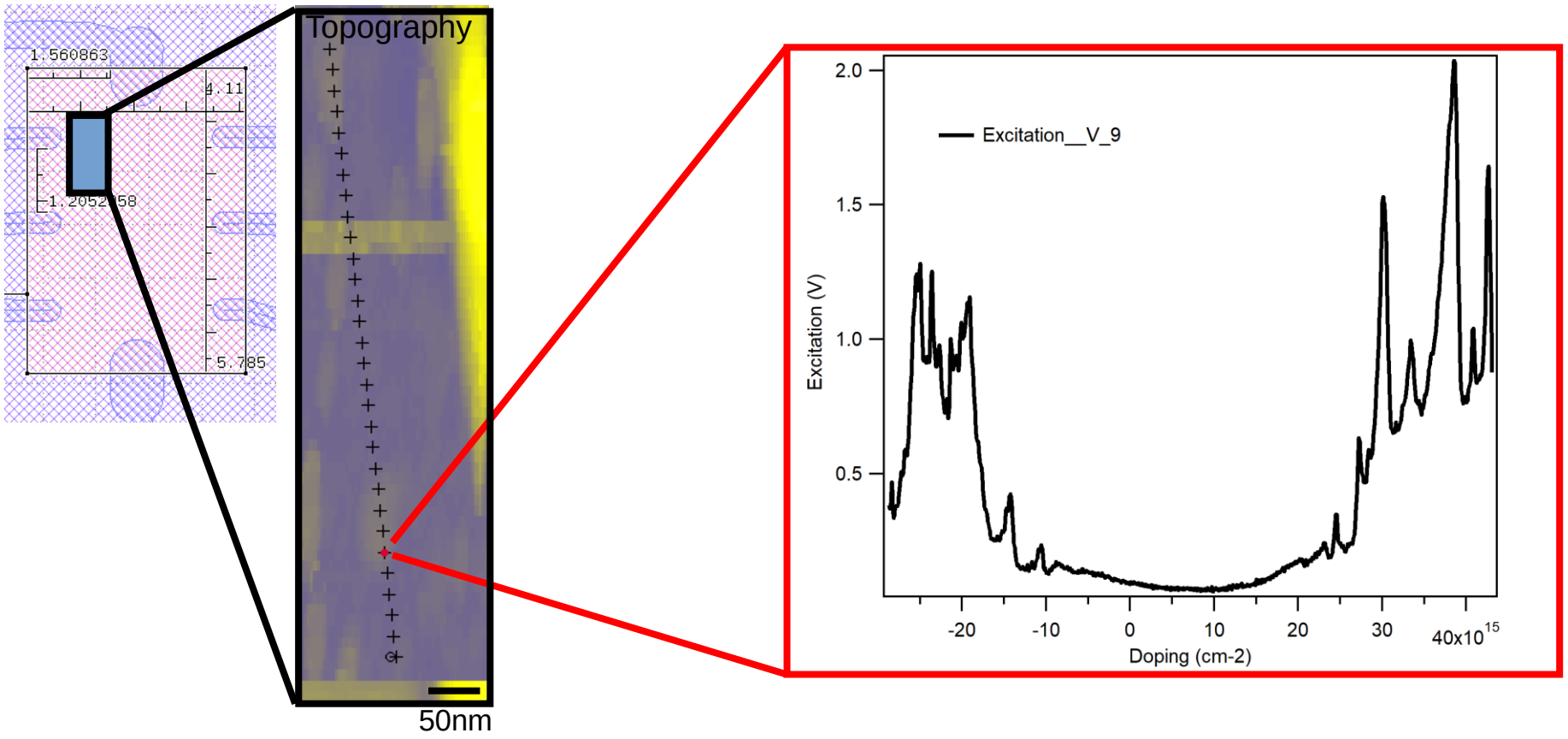
Due to disorder, the spatially averaged DOS at Dirac point is not zero. A disorder density $n_d = 5 \cdot 10^9 cm^{-2}$ can be calculated from CPD shift.

($n_d \approx 1 \cdot 10^{10}$ cm^{-2} in Cao et. al. case)



RESULTS

• Twist angle distribution



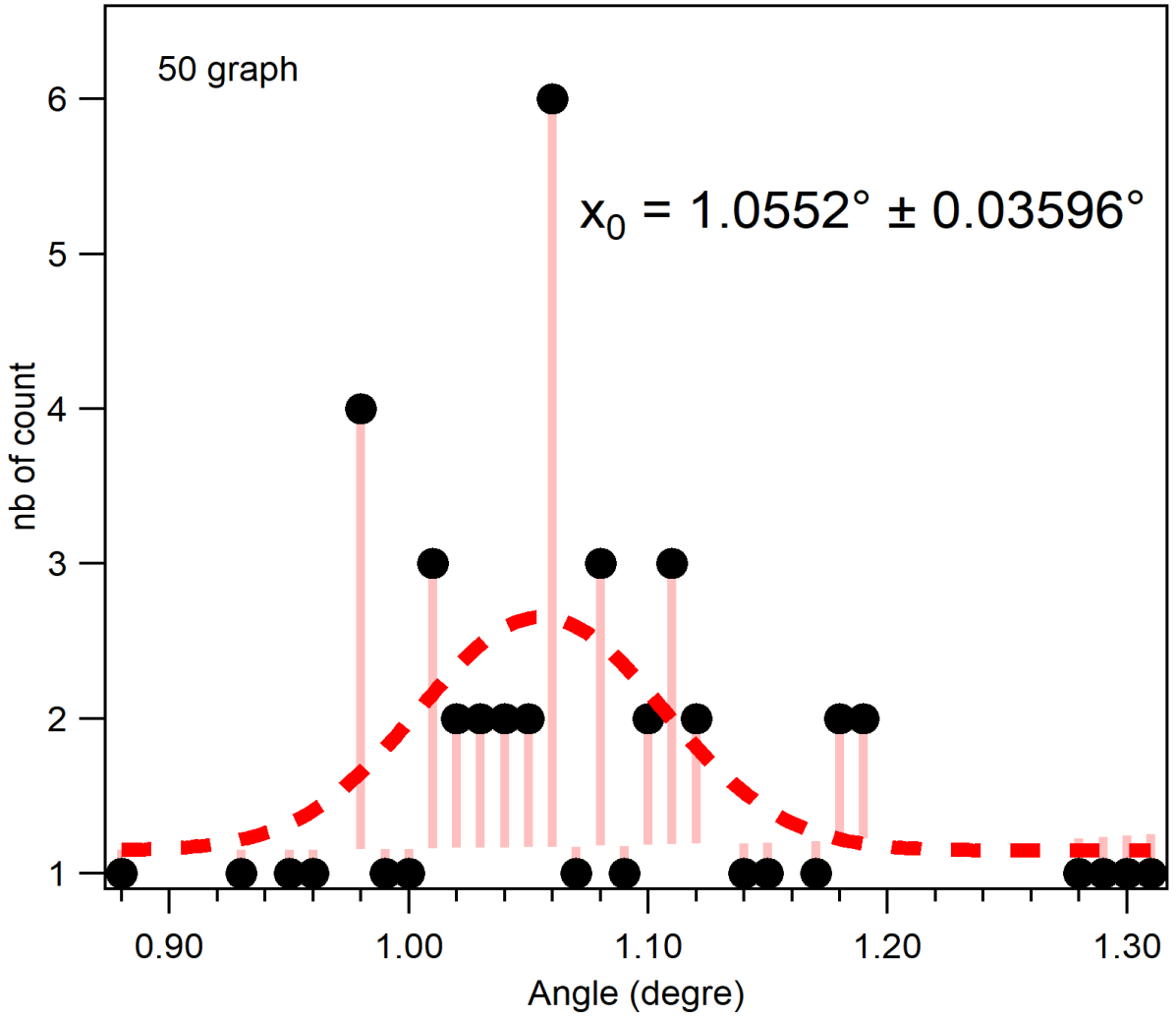
We measured dissipation spectra at every point along the line (30 points). Next, we match the position of the dissipation peaks to the superlattice density n_s. Thus, we can locally determine the twist angle : $\theta = \left(\frac{3}{64}\right)^{14} \cdot \sqrt{n_s} \cdot a$

RESULTS

• Twist angle distribution

The twist angle is equal to 1.06° ± 0.04°

Twist angle distribution is only 3-4% off from the magic twist.

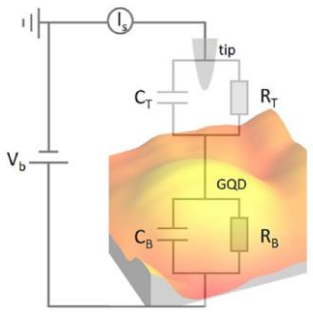


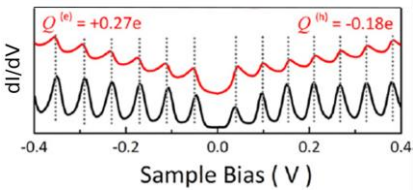
RESULTS

• Constant height dissipation maps

The angle distribution is also visible in constant height dissipation images where we observe domains with different relaxation of the graphene (dashed lines).

Graphene quantum dot (CB=Coulomb Blockade)



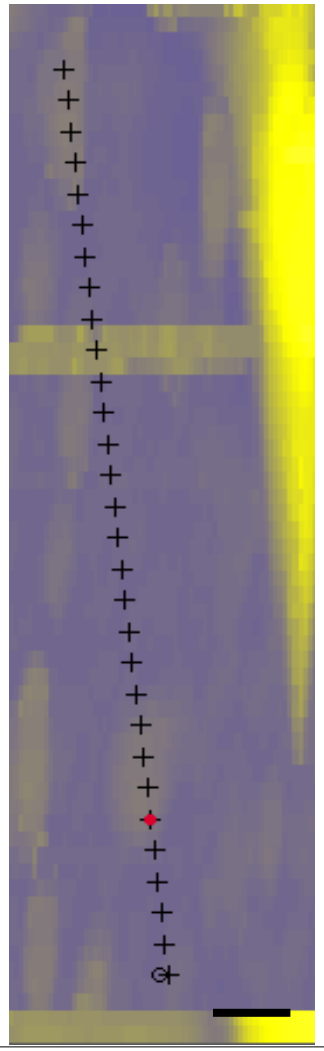


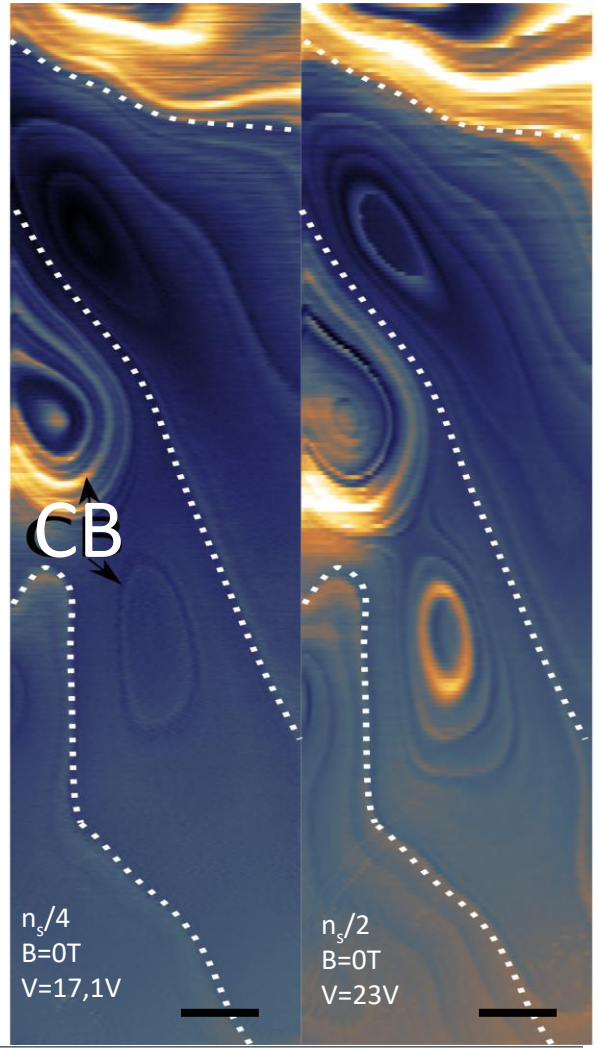
Qiao, Jia-Bin and Jiang et.al., ***Bound states in nanoscale graphene quantum dots in a continuous graphene sheet****, PRB95, 081409 (2017).*

Scale bar = 50nm

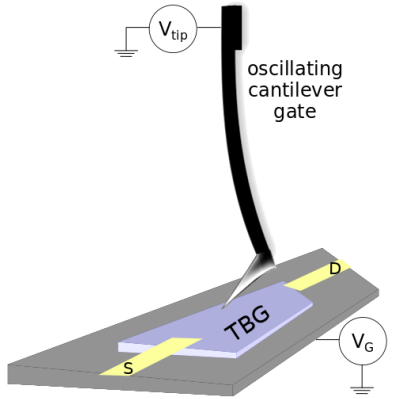
Topography

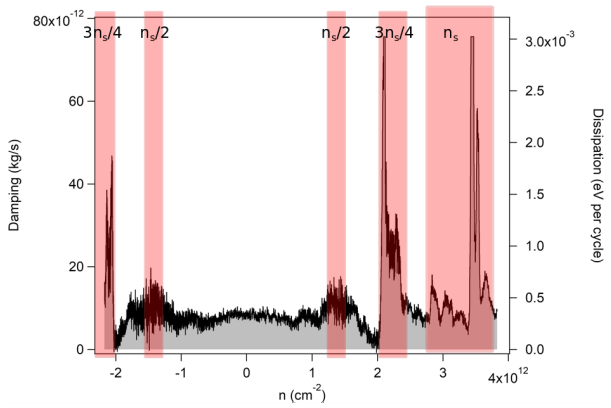
Energy dissipation images





CONCLUSIONS



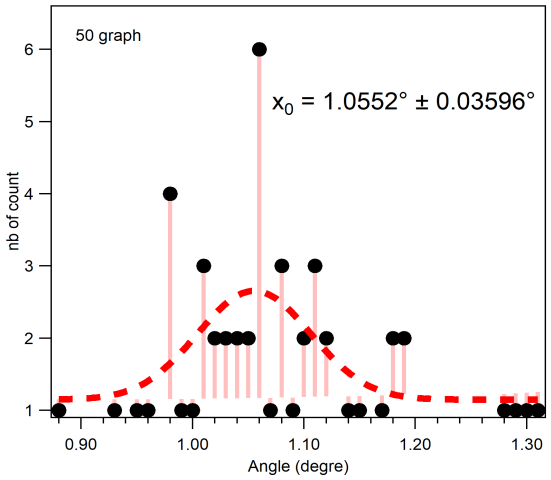


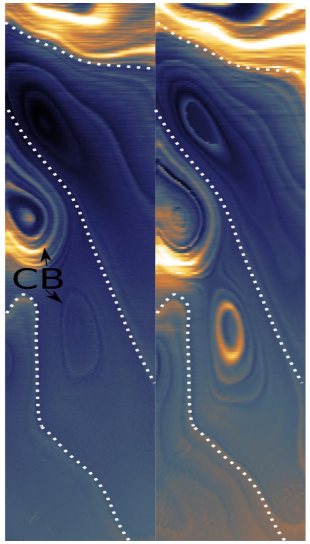
P-AFM spectroscopy:

- local probe tool,
- can study band filling of TBG:
  - ▸Energy dissipation is sensitive to charge filling of flat bands,
  - ▸Dissipation peaks: ¼ filling, half filling , filling and full filling,
  - ▸Rise of frictional lose at CNP, (electron-hole scattering).

Angle distribution investigation:

- Quantitative: average angle of 1.06° and angle distribution about 3-4%
- Qualitative: the constant height tip imaging allows to map the twist angle distribution of TBG and observe CB rings.





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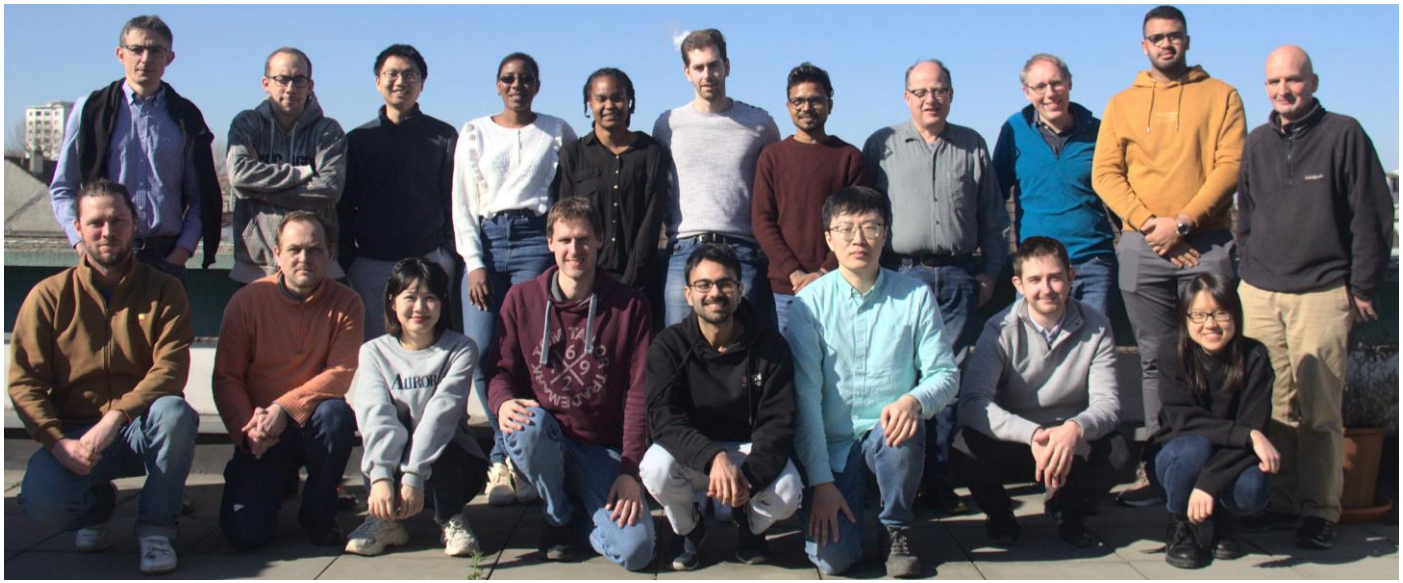

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Thank you for your attention !