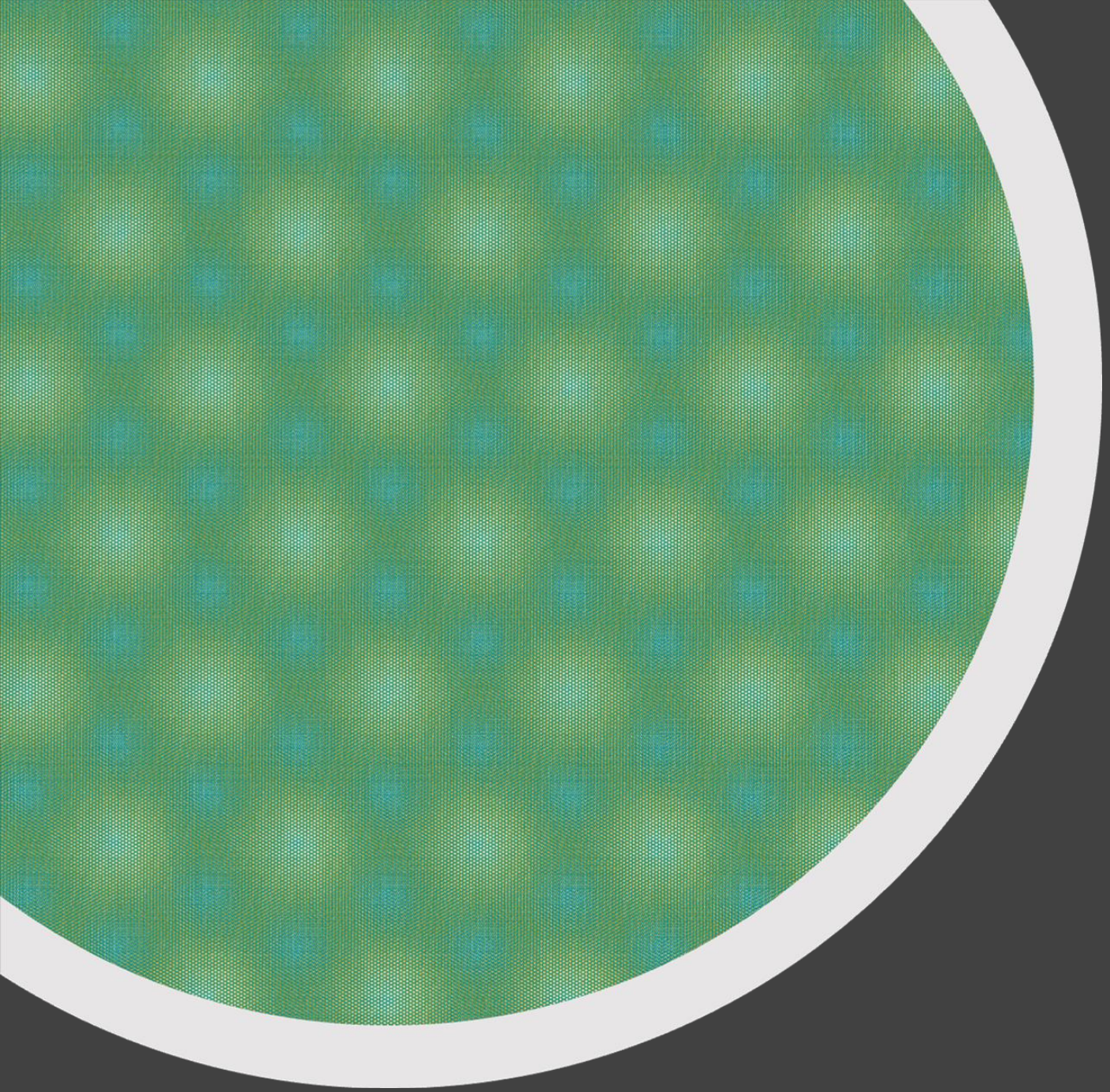


Controlling graphene-hBN rotational alignment

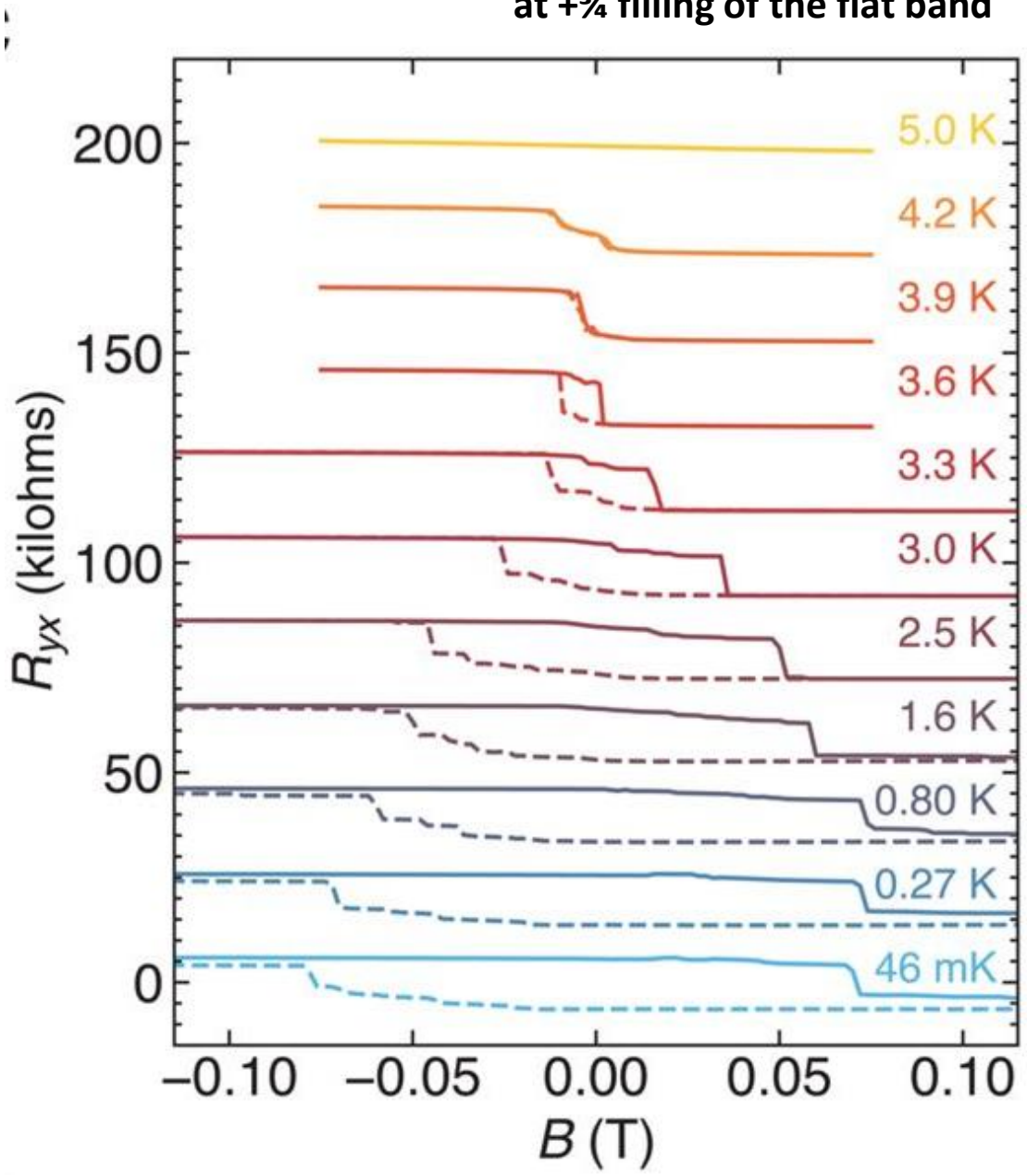
A critical parameter for graphene-based moiré heterostructures

Rupini Kamat

Goldhaber-Gordon Group
Stanford Physics Department
Stanford Institute of Materials and Energy Sciences

A very special magnet

at +¾ filling of the flat band



[1] A. Sharpe, et al. S*cience* 365.6453 (2019): 605-608

Goldhaber-Gordon Group, Stanford

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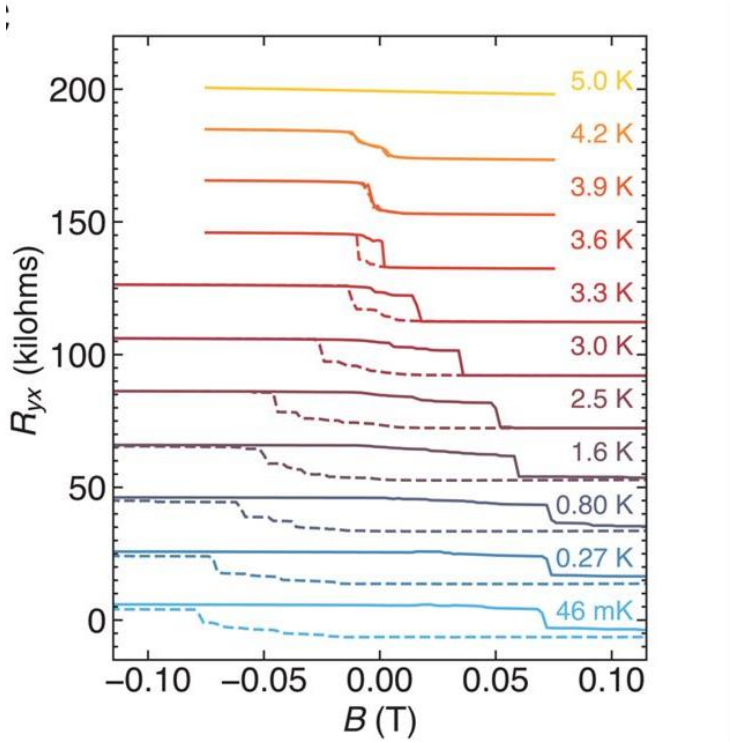

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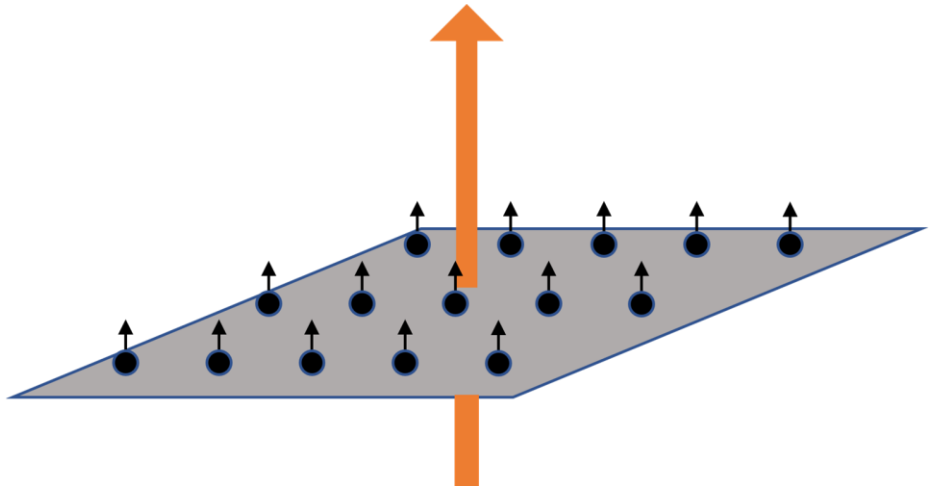
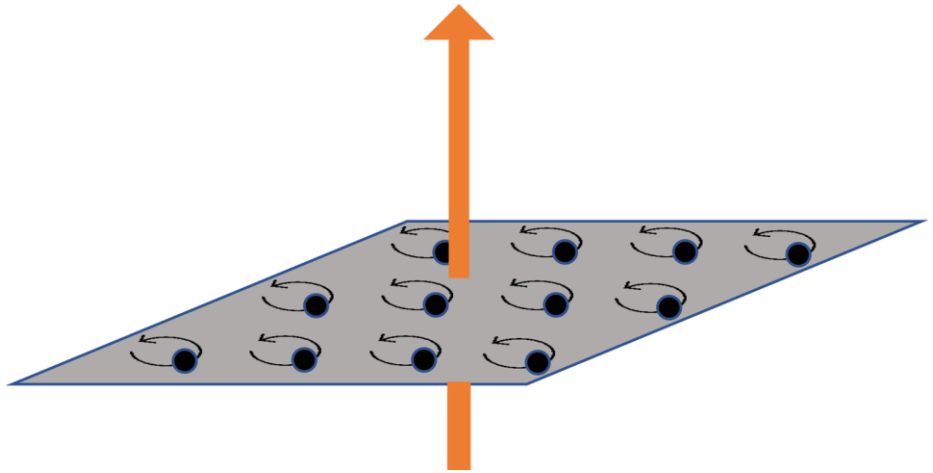
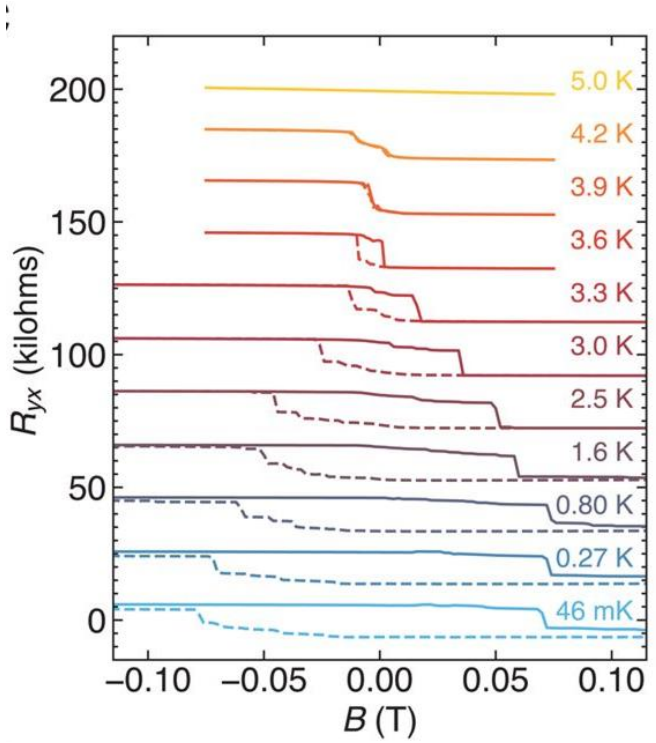


Spin Ferromagnet



Orbital Ferromagnet

A very special magnet



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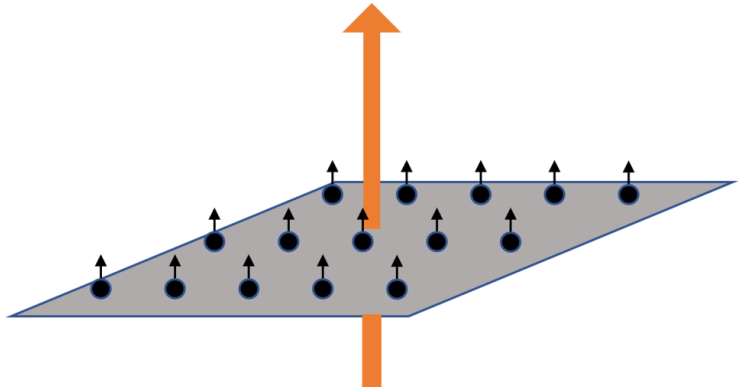

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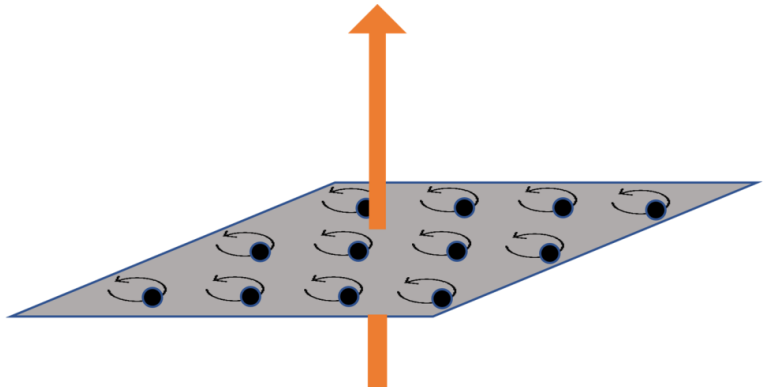

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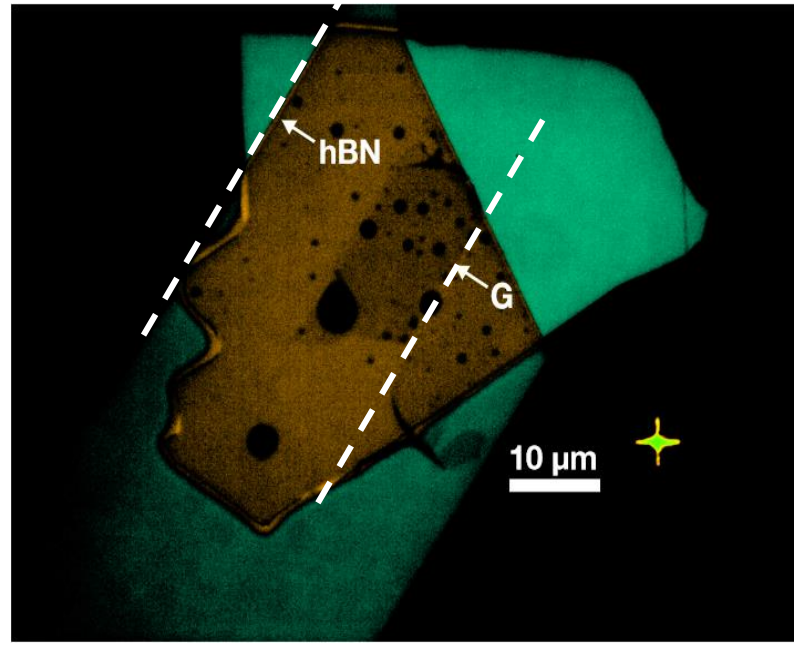
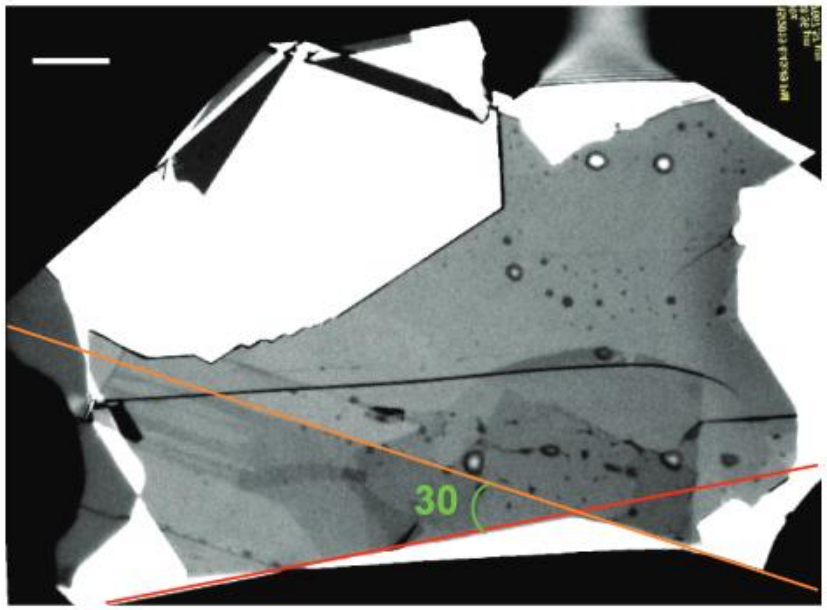
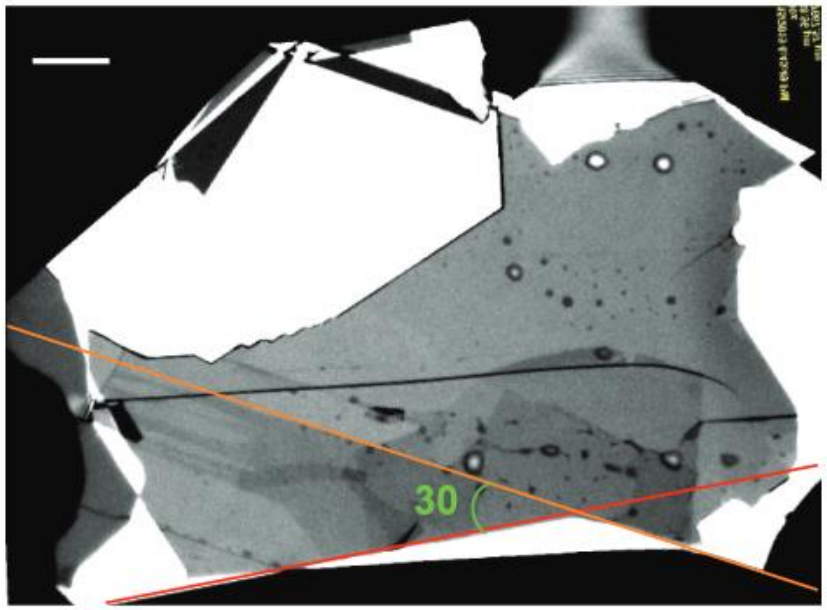


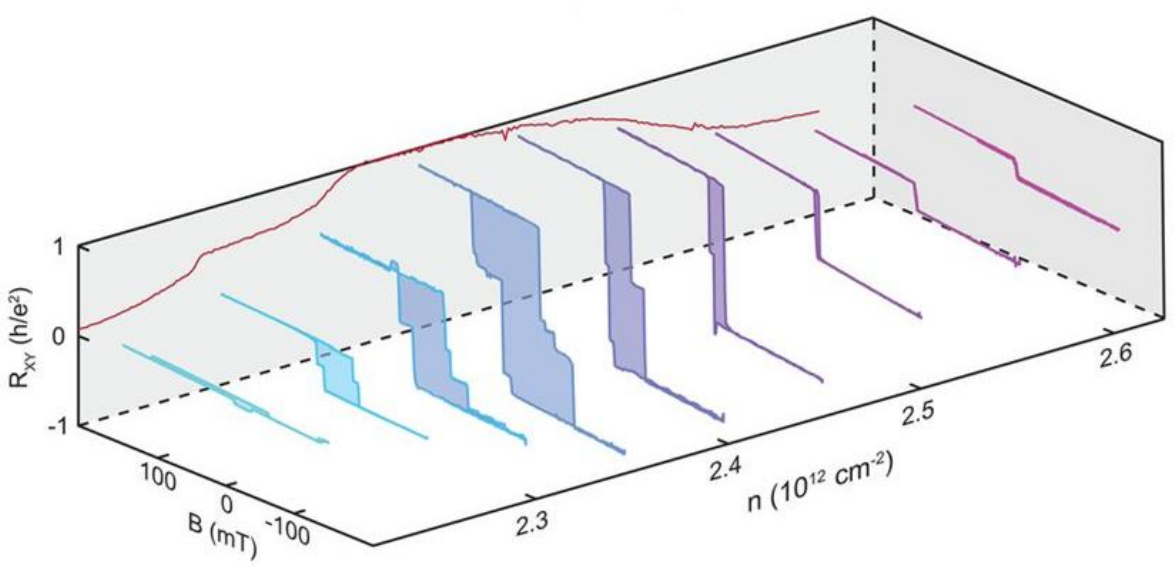
Another hBN-aligned TBG sample



[3] M. Serlin, et al. *Science* 367.6480 (2020): 900-903
Young Group UCSB

Confirmation/extension!





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A problem

- 3 years and hundreds of MATBG samples later…
  Still only 2 ferromagnetic TBG samples with this phase diagram

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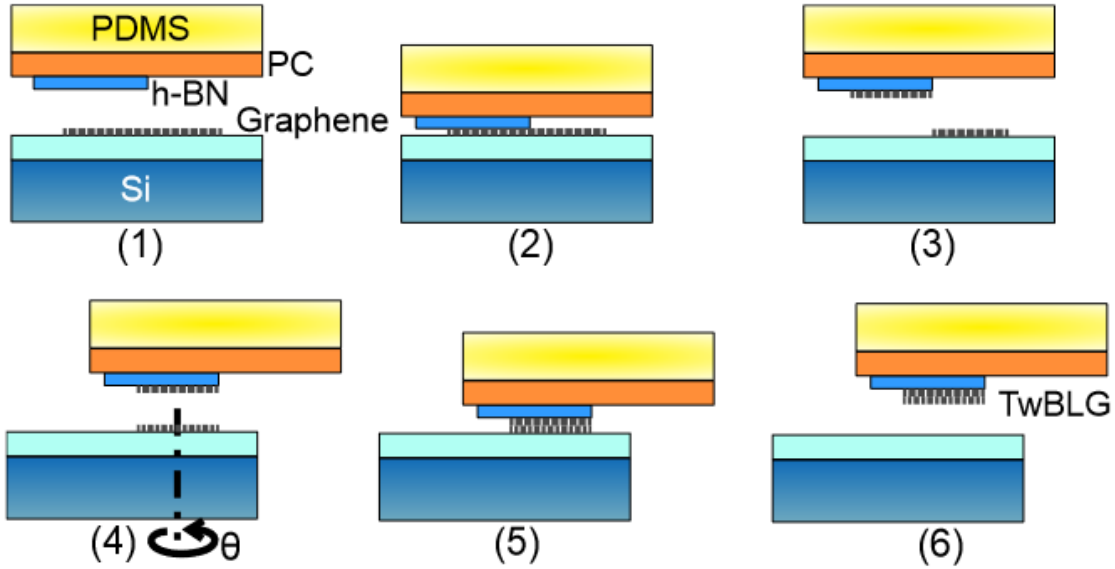

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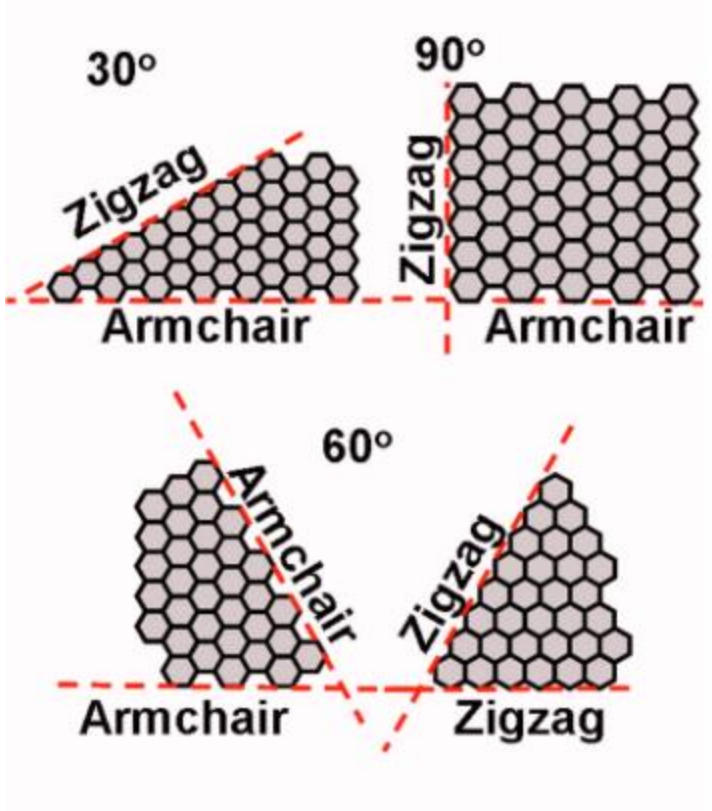

	ZZ	AC
ZZ	✓	X
AC	X	✓

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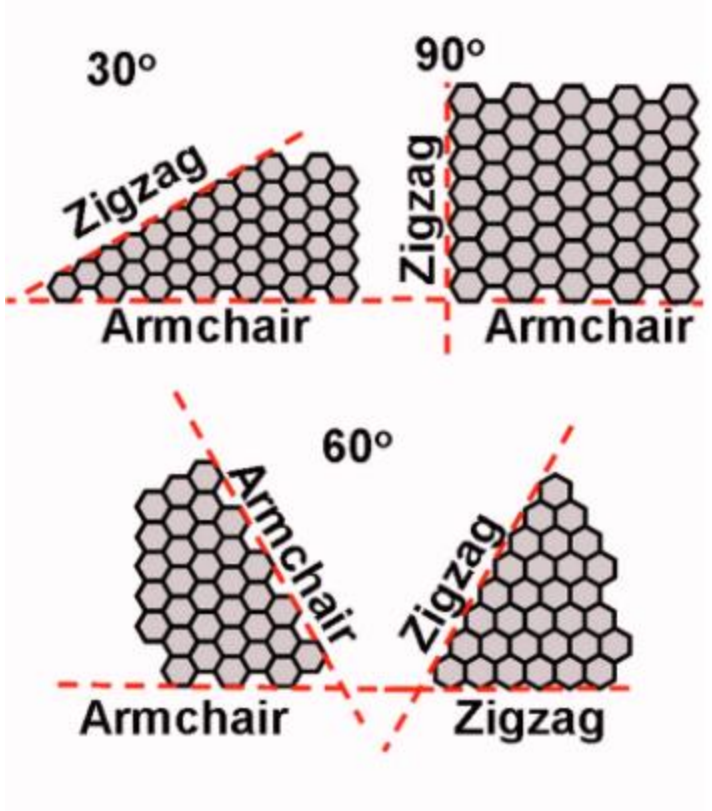

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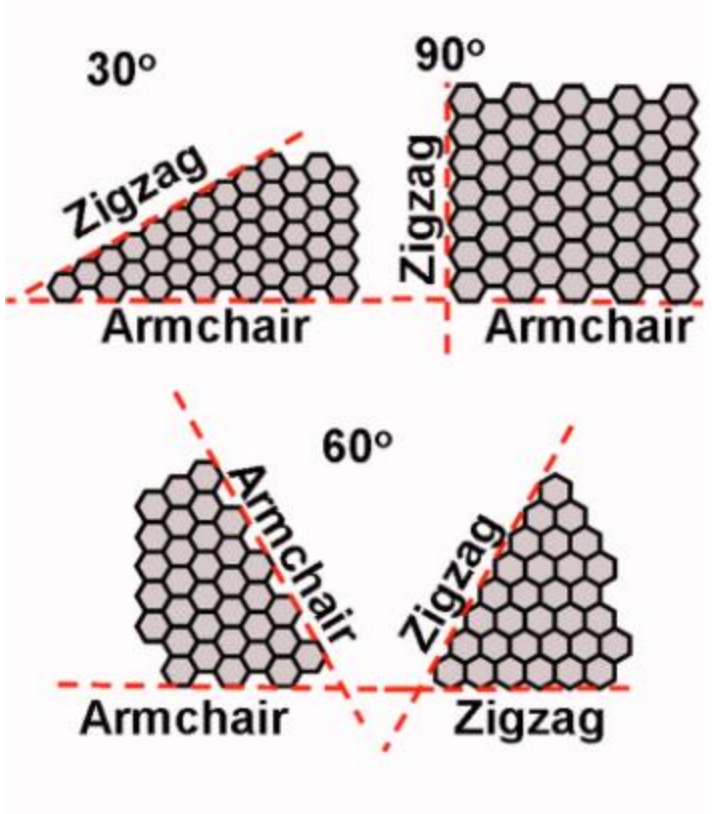

Need greater control.

Strategy: 1) Characterize straight edges in flakes as ZZ or AC prior to stacking
2) Characterize moiré period after stacking.

	ZZ	AC
ZZ	✓	X
AC	X	✓

Graphene Orientation: Polarized Raman

[5] L. G. Cancado, et al. *Physical review letters* 93.24 (2004): 247401.
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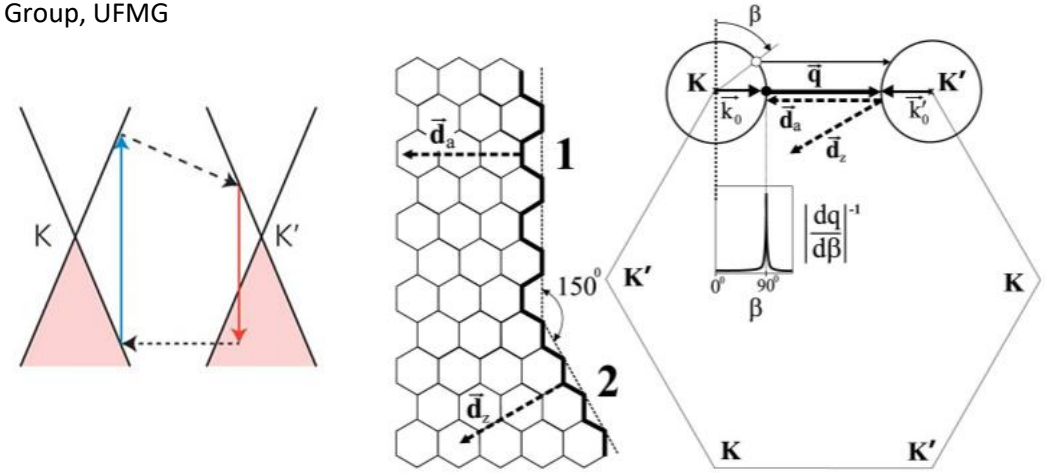

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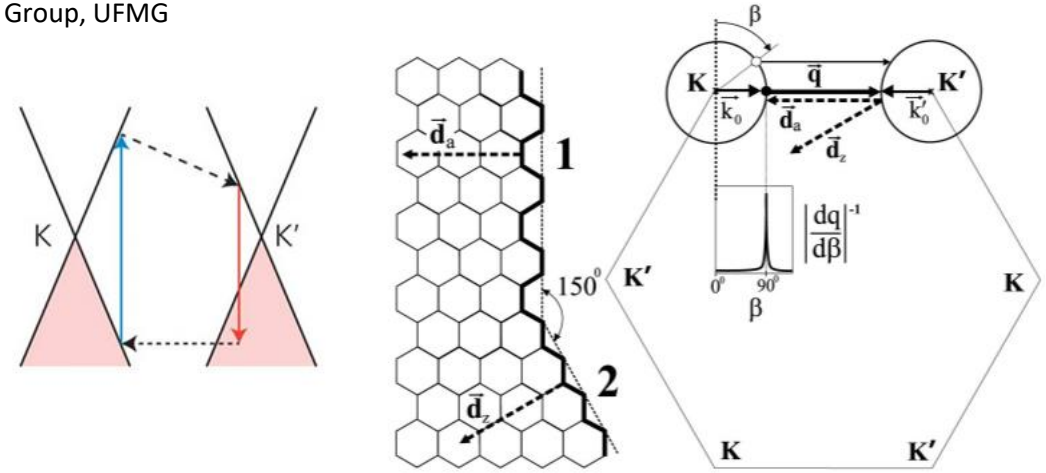

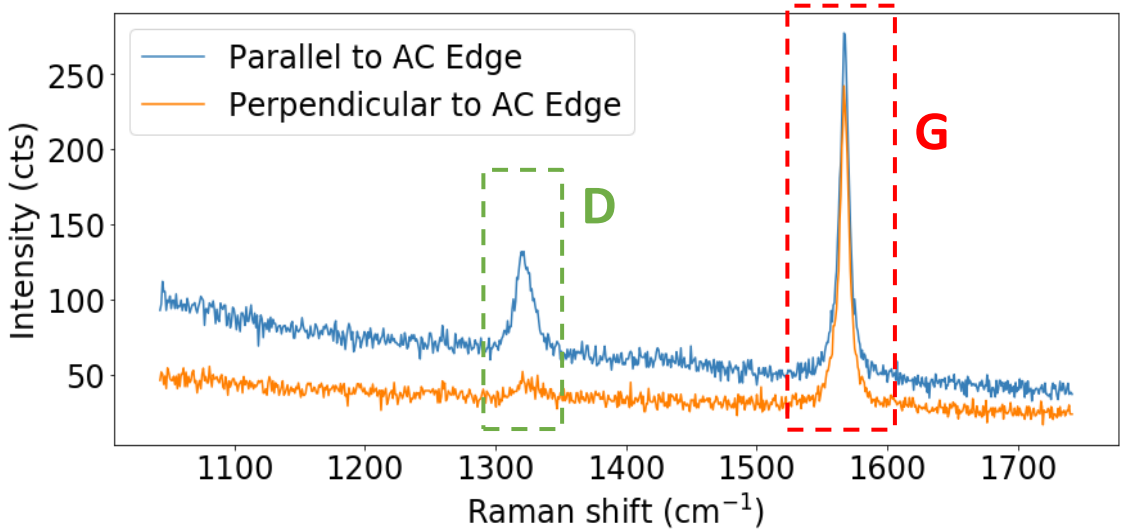

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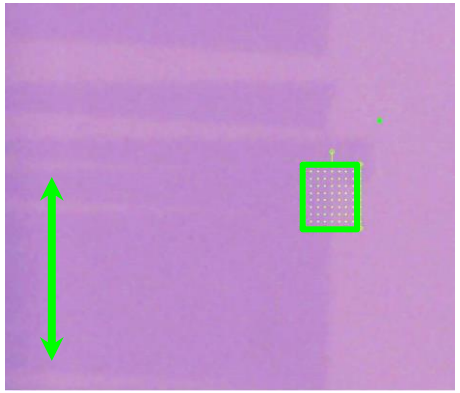
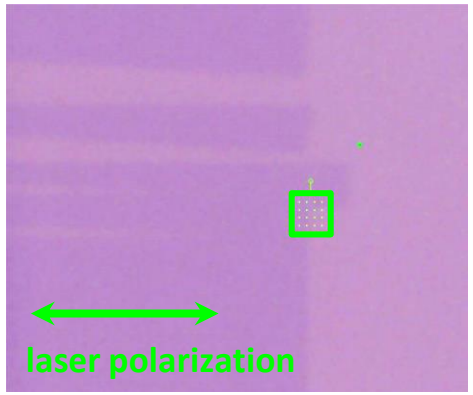
Raman Characterization of Graphene Orientation: An Example





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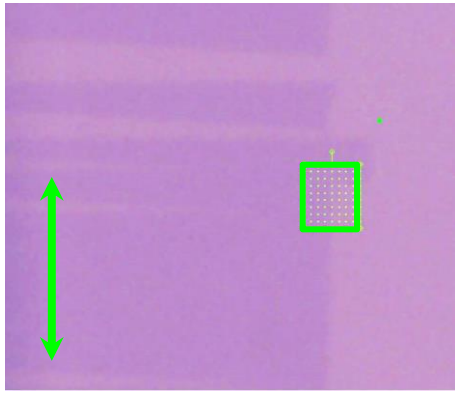

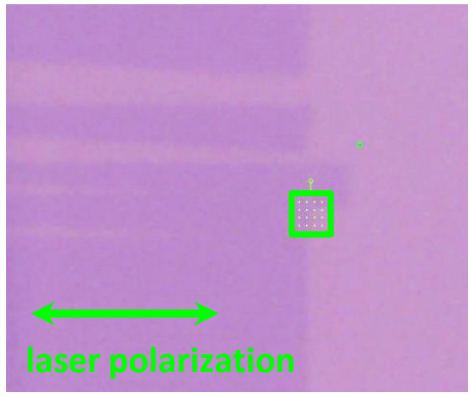

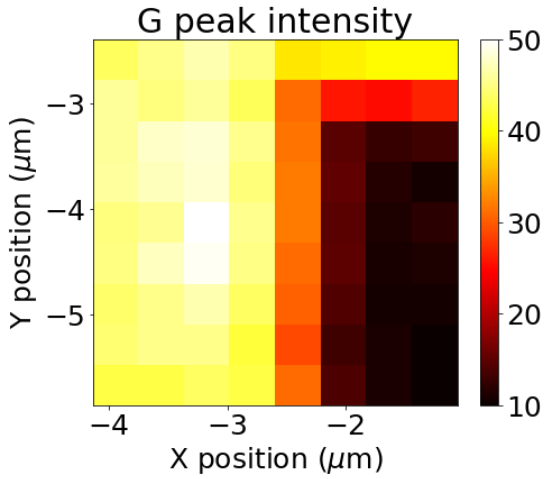

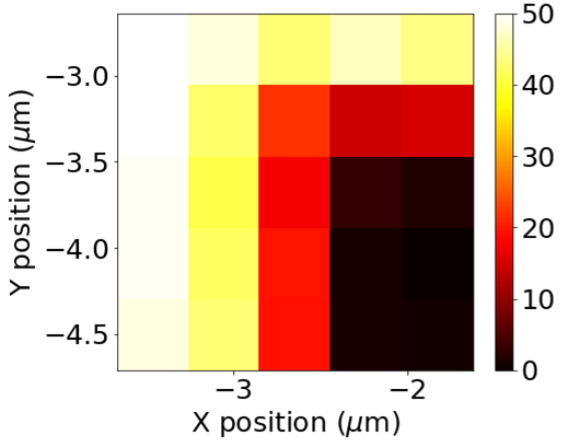

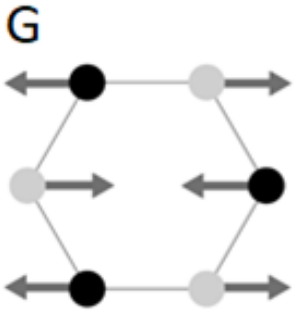

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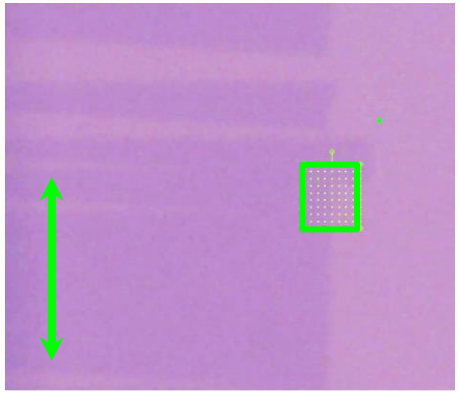
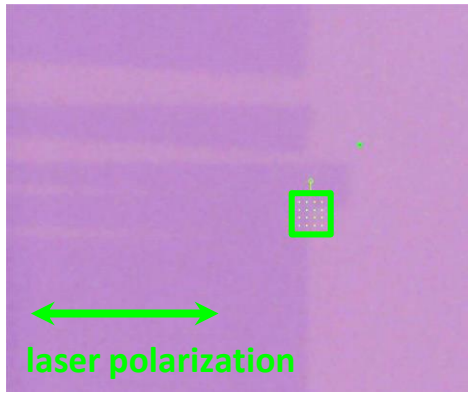
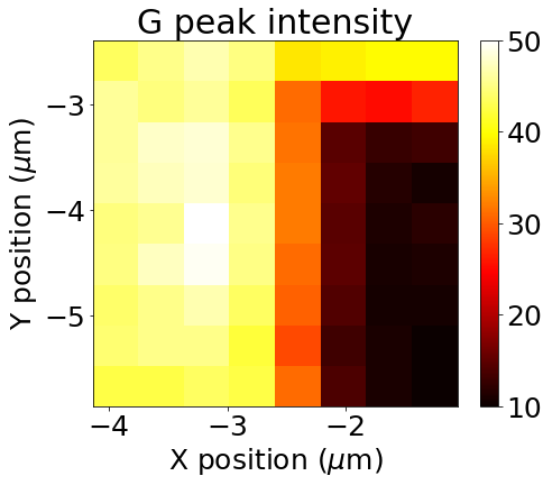
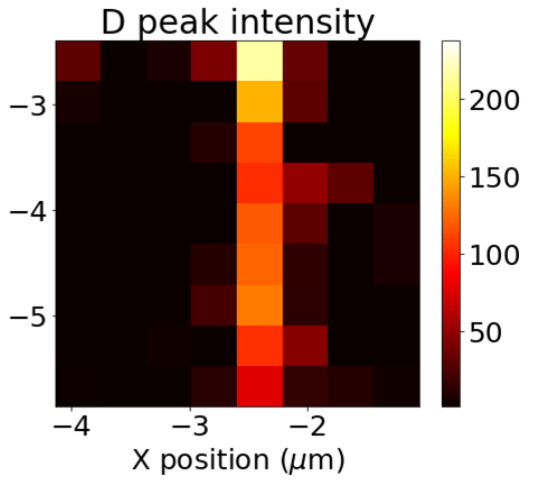
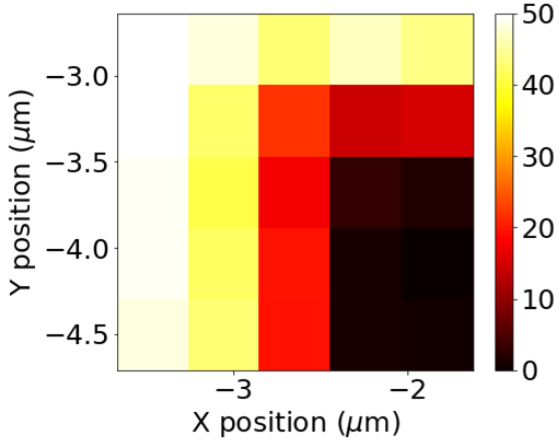
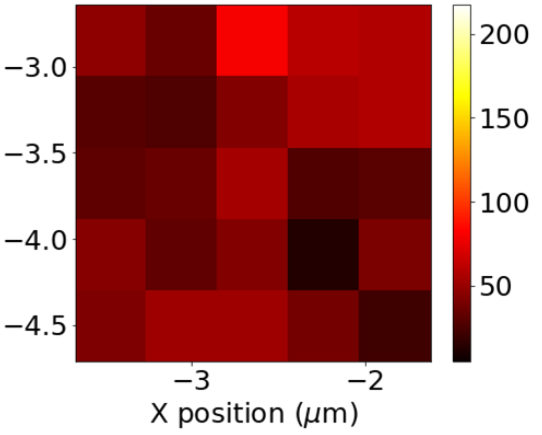




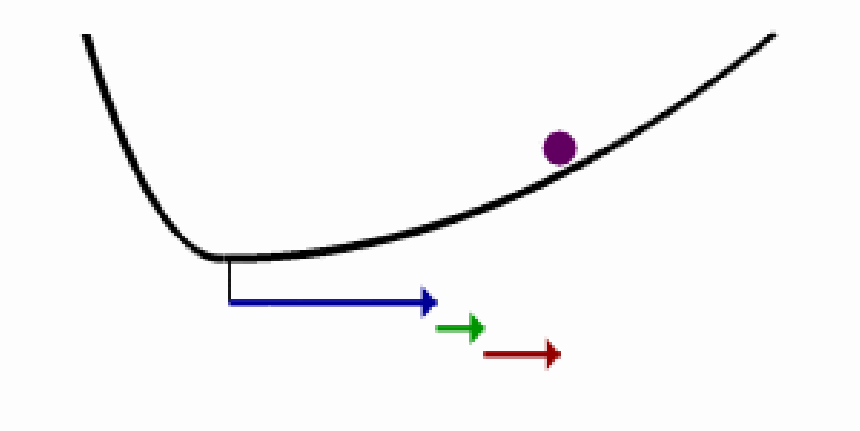








hBN Orientation: Second Harmonic Generation



- Non-centrosymmetric materials pumped by laser light at frequency *f* emit a second harmonic signal at 2*f*

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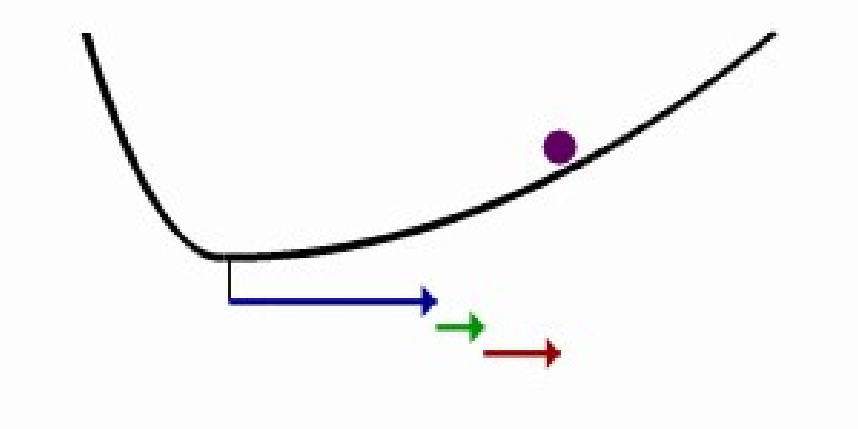

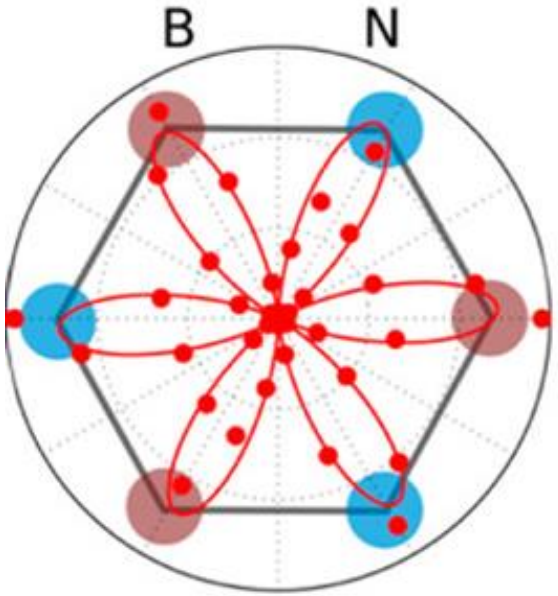

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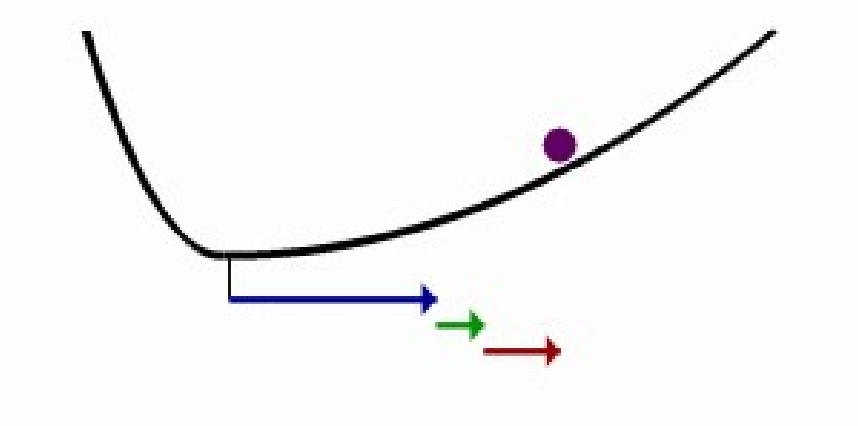

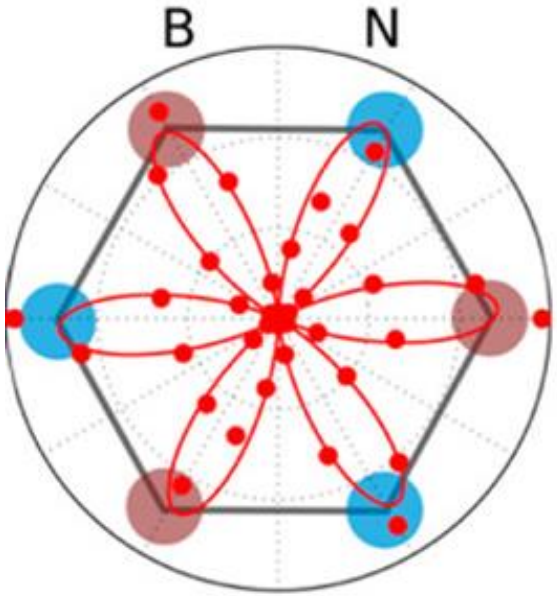

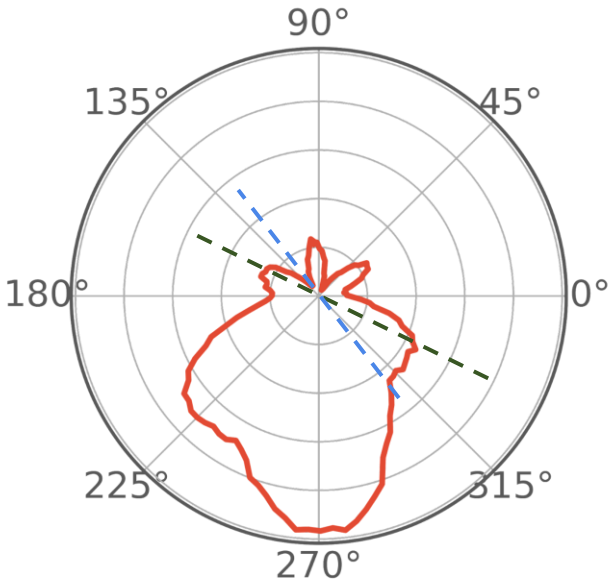

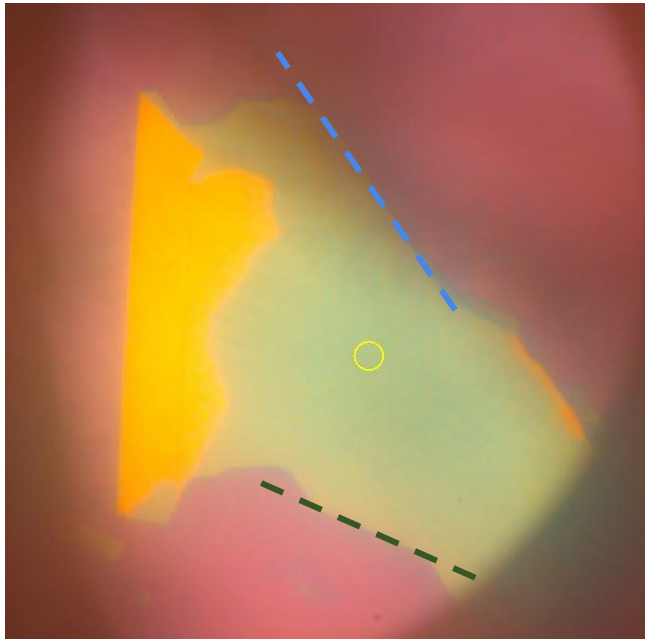

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Post-Stack Characterization: Piezoresponse Force Microscopy (PFM)

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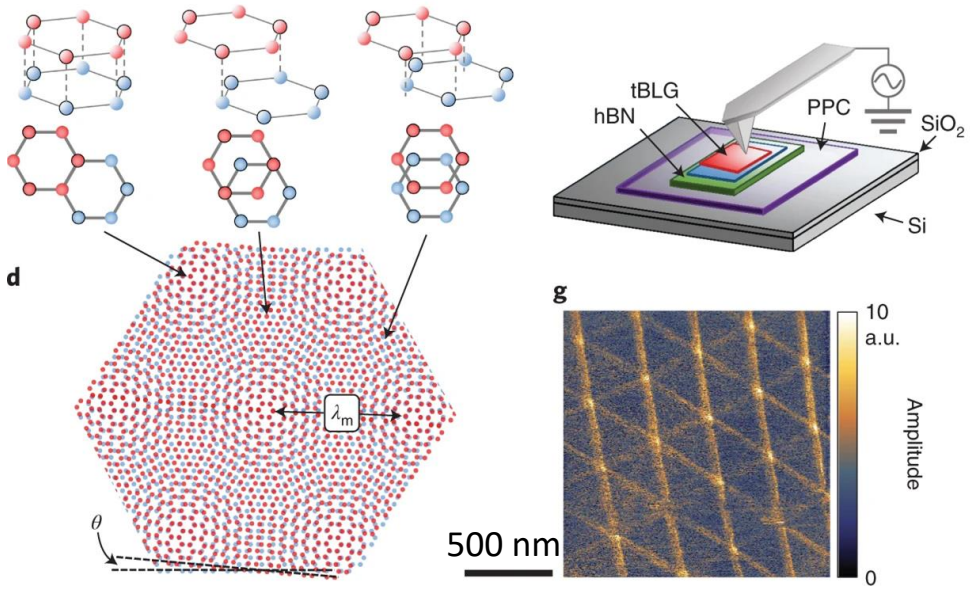

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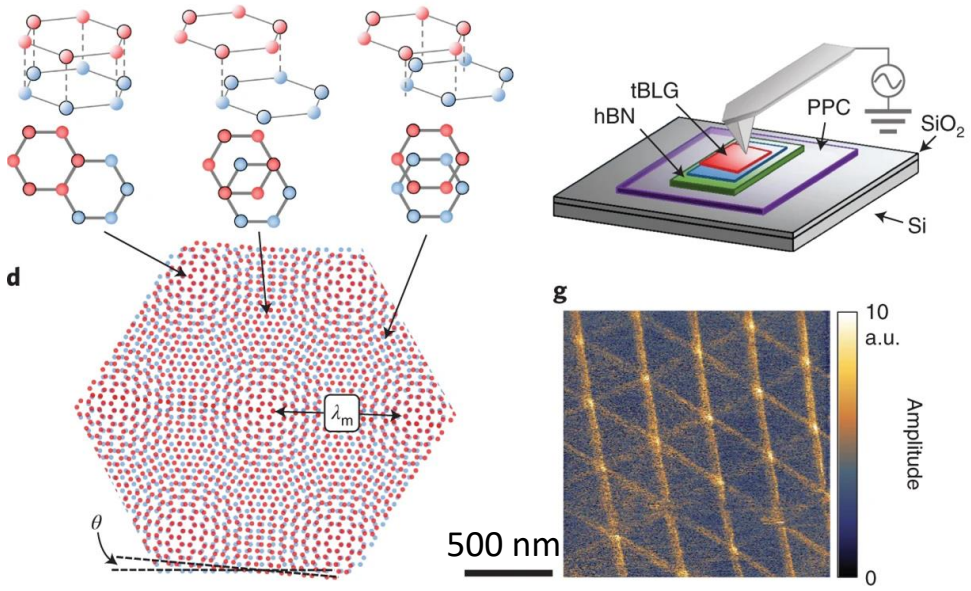

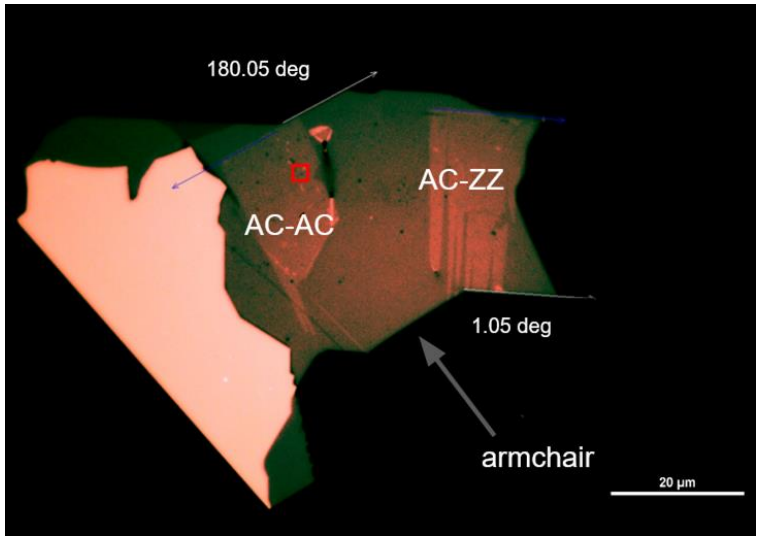

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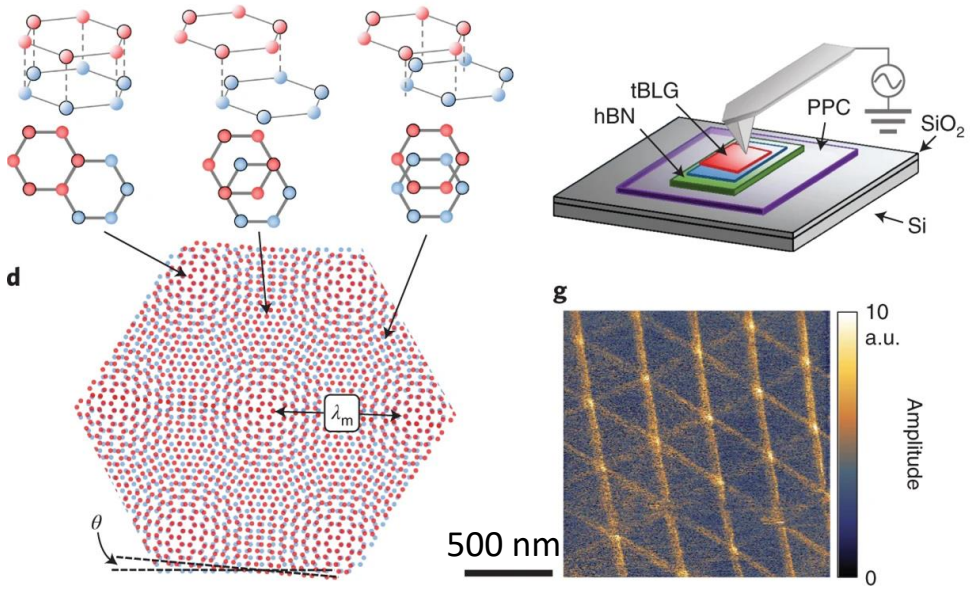

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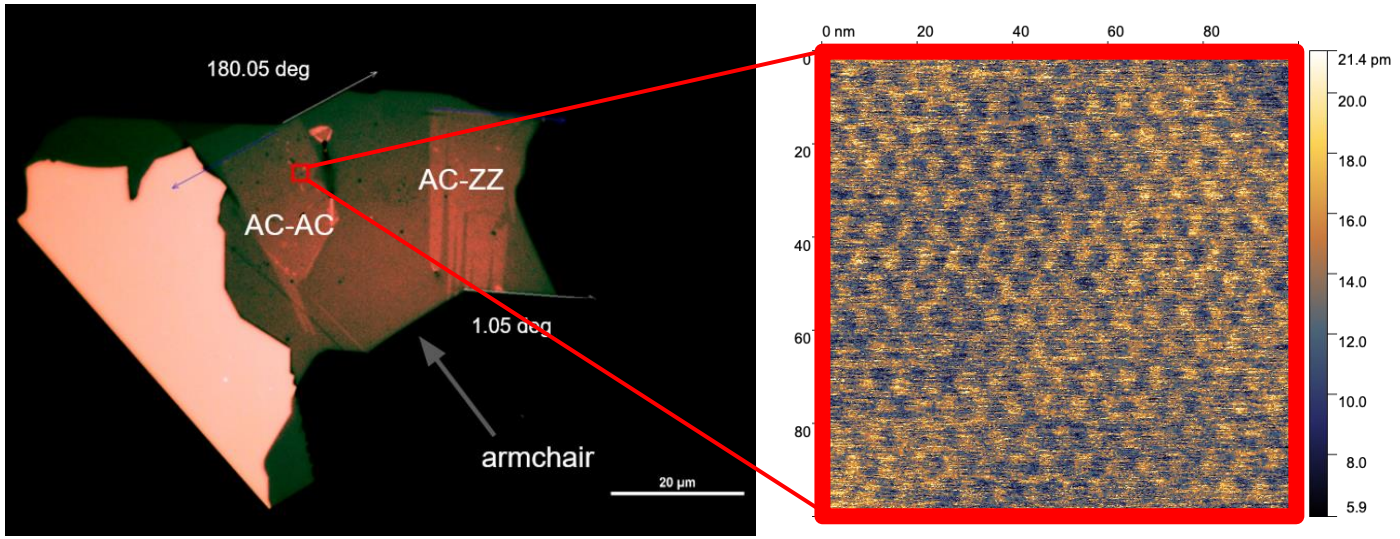

Early results confirm successful alignment using pre-stack characterization!

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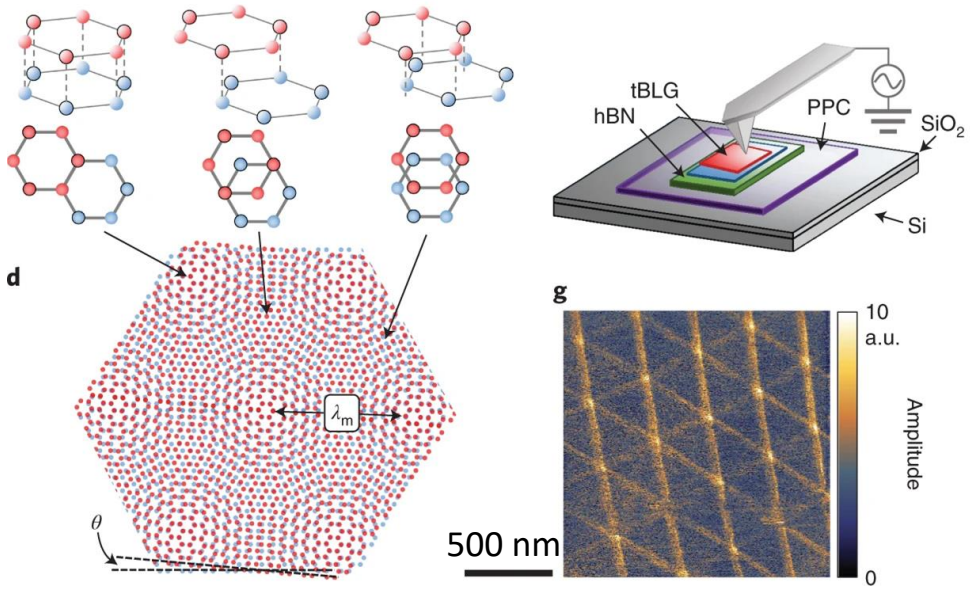

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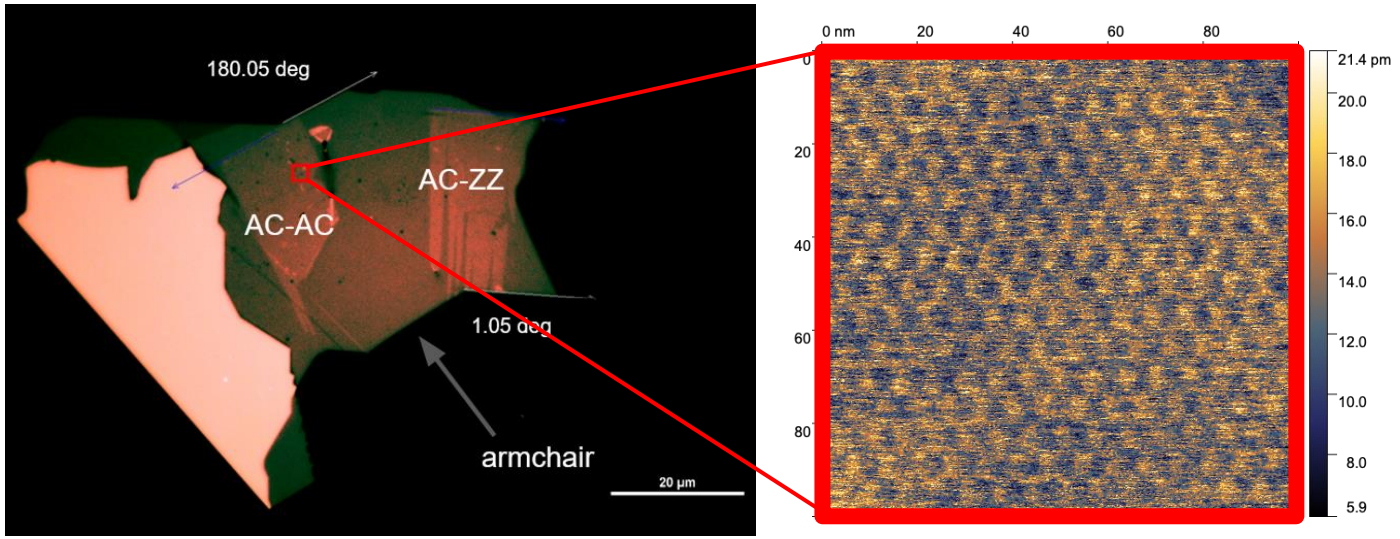

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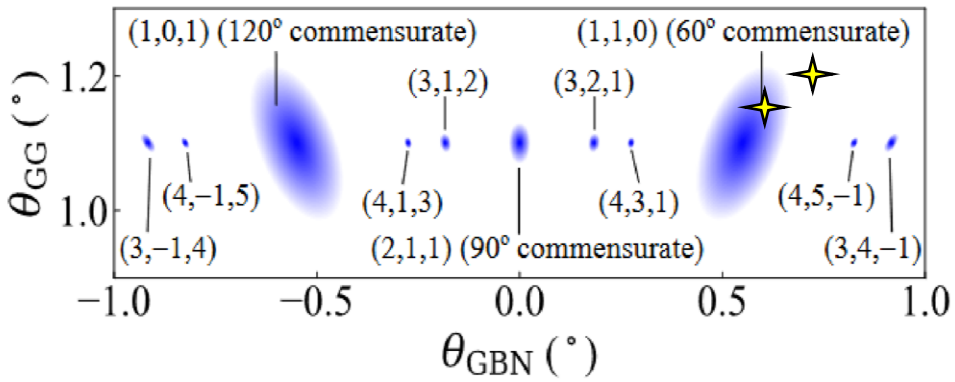
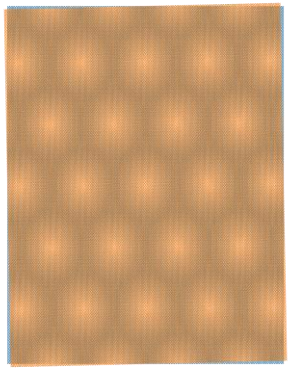
Precise alignment remains a challenge, moire period ~7.2 nm moire period→ 1.69 deg twist angle

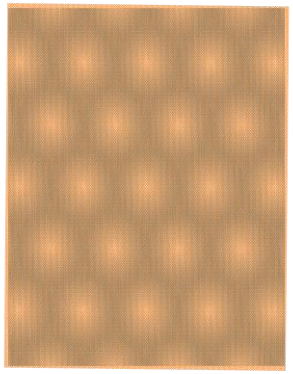
Outlook



[8] J. Shi, et al. *Physical Review B* 103.7 (2021): 075122. MacDonald Group, UT Austin



θ_{GG} = 1.15°



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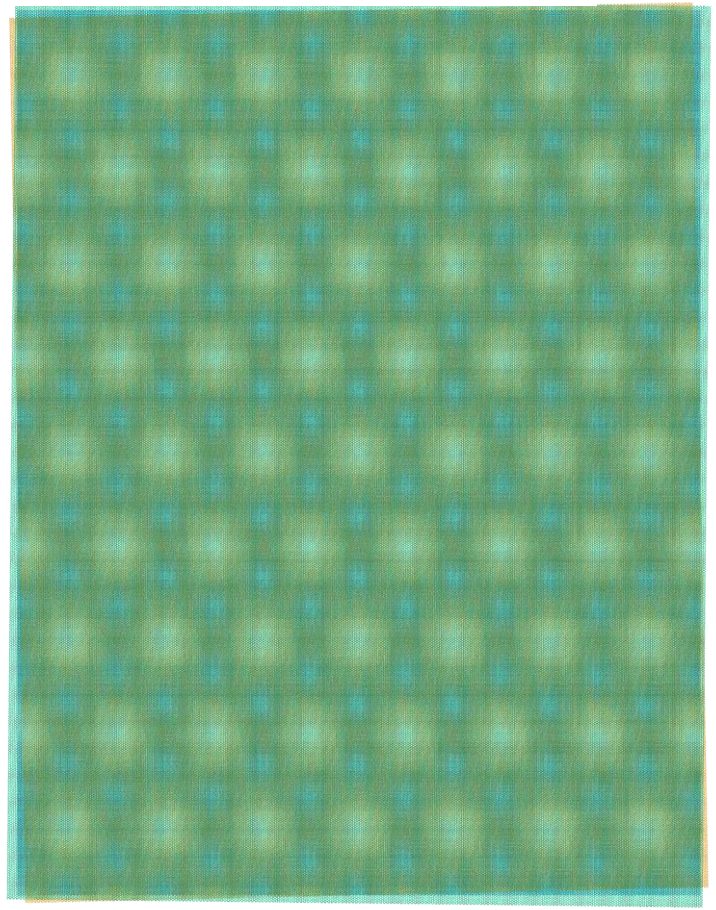


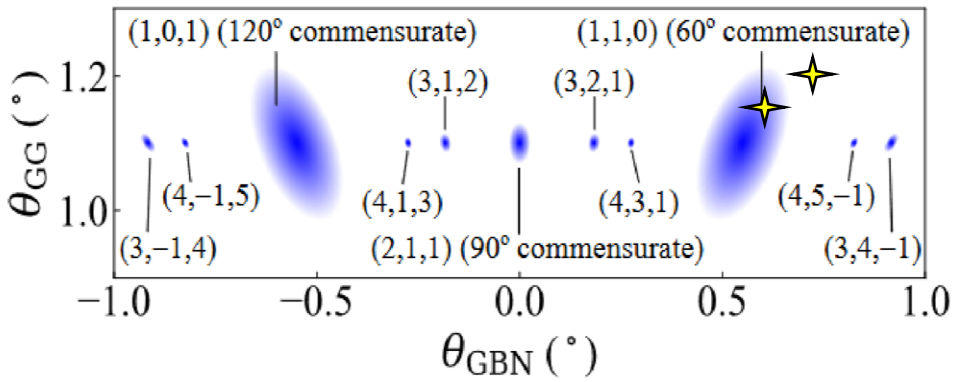
Outlook

❖Process flow of pre-stack characterization/stacking/post-stack characterization enables new degree of control AND verification of Gr-hBN moiré

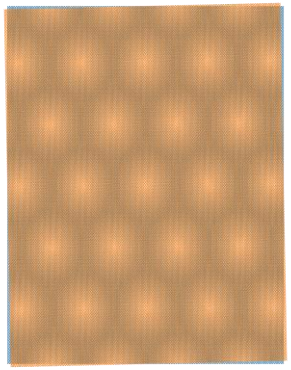
Combining these tools can enable:

1) **reliable reproduction of novel correlated electron states (like orbital ferromagnetism in TBG) that may depend on this supermoiré**

1) **systematic exploration of device behavior as a function of graphene-hBN alignment.**



[8] J. Shi, et al. *Physical Review B* 103.7 (2021): 075122. MacDonald Group, UT Austin



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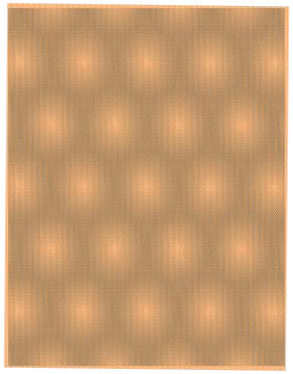

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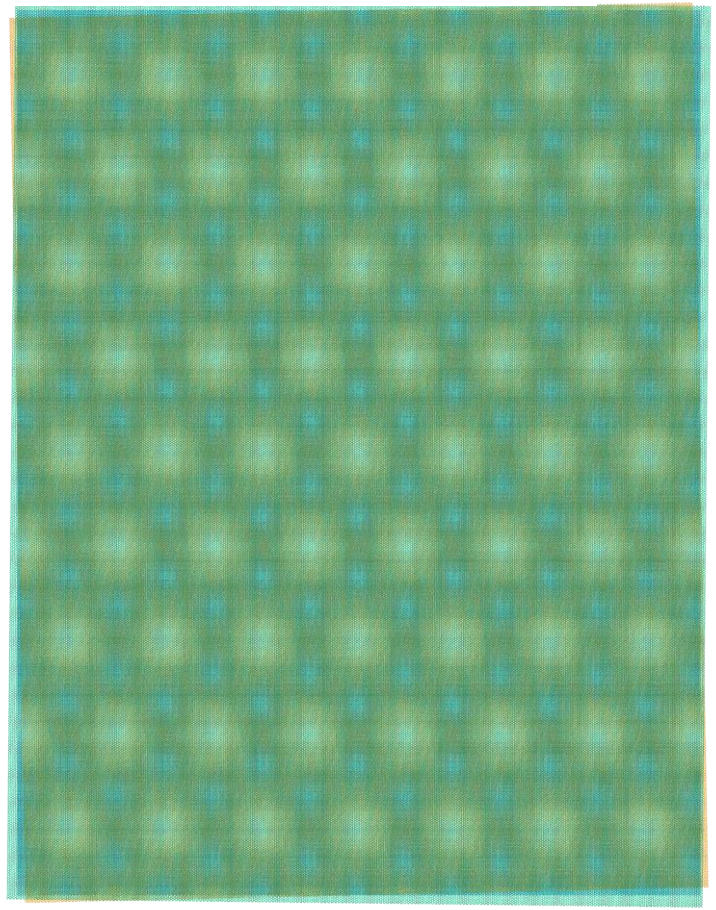
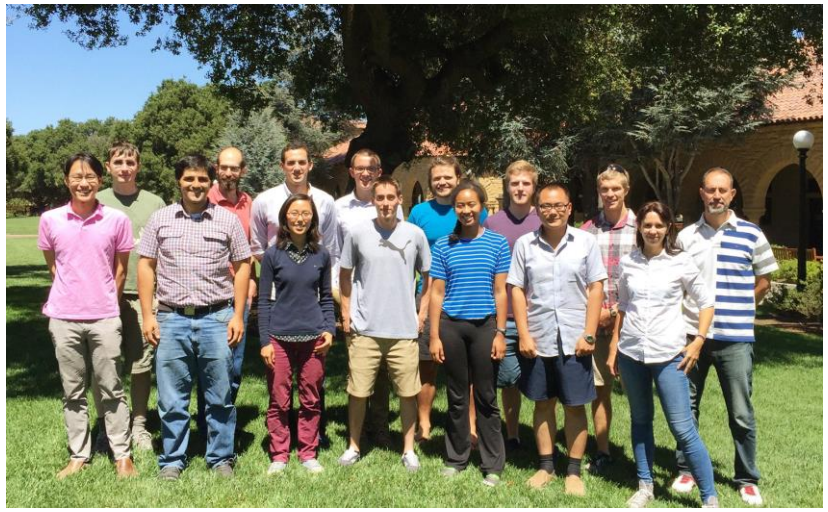


Acknowledgments



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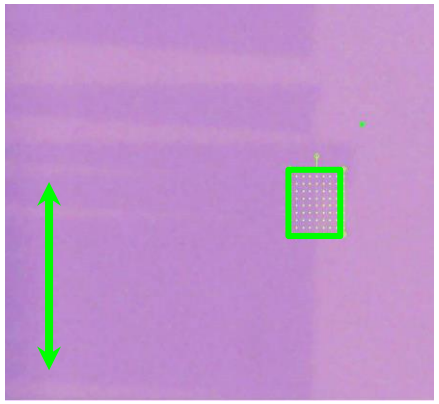
NIMS:
Takashi Taniguchi, Kenji Watanabe

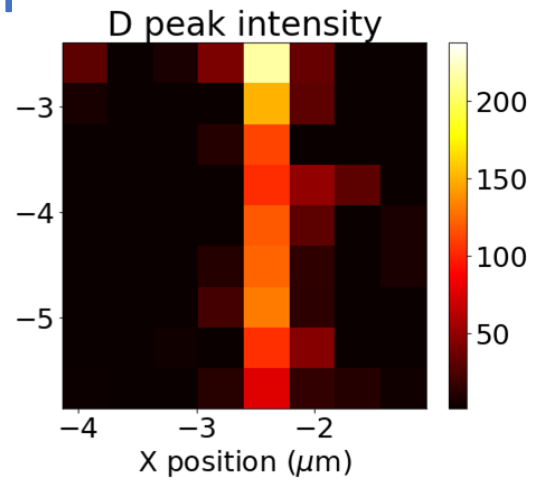
Funding acknowledgement:

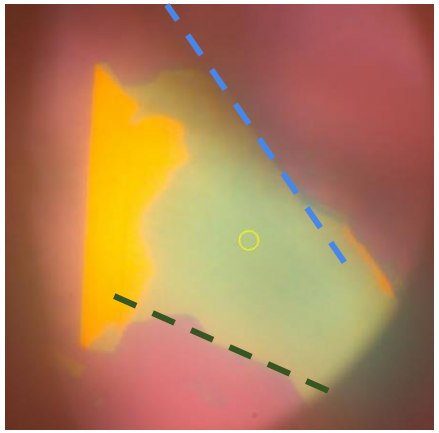
Stanford Institute for Materials and Energy Sciences **GRFP**

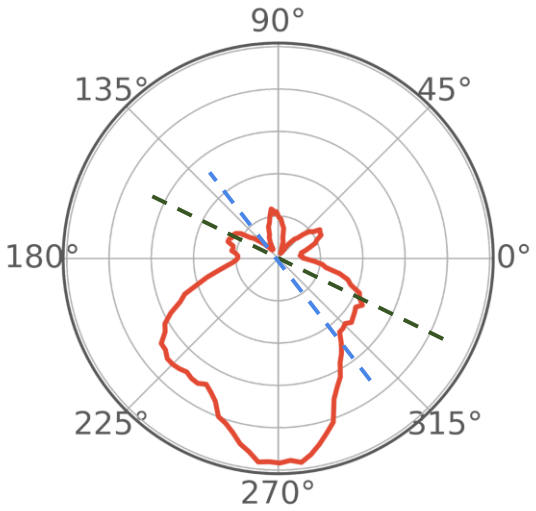
Questions?

Pre-Characterization

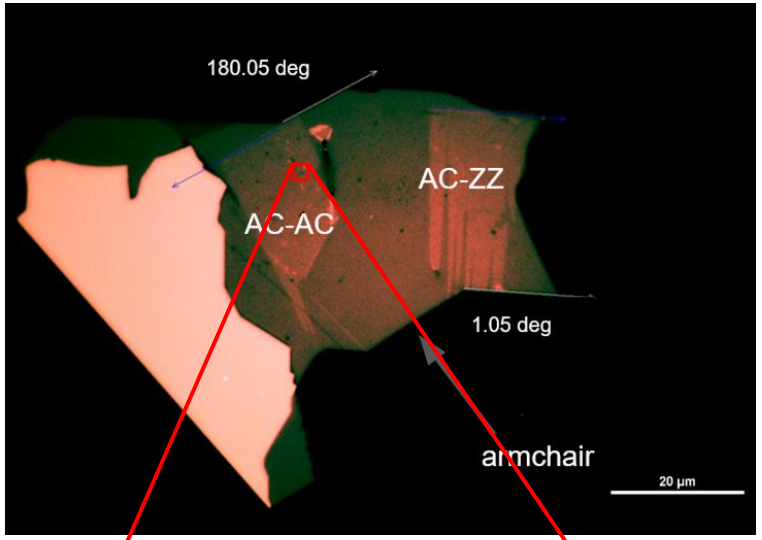


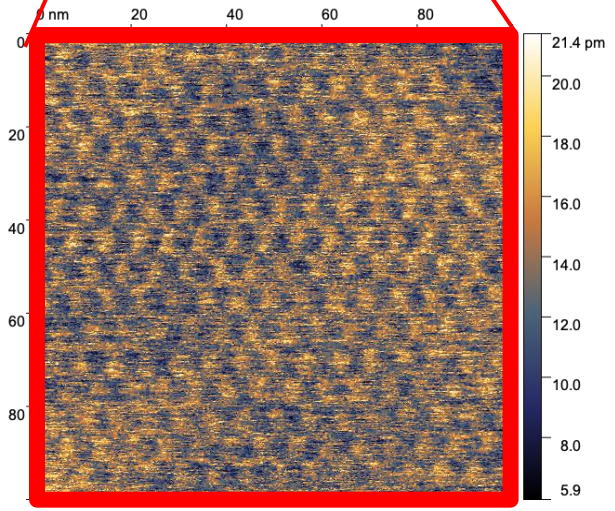




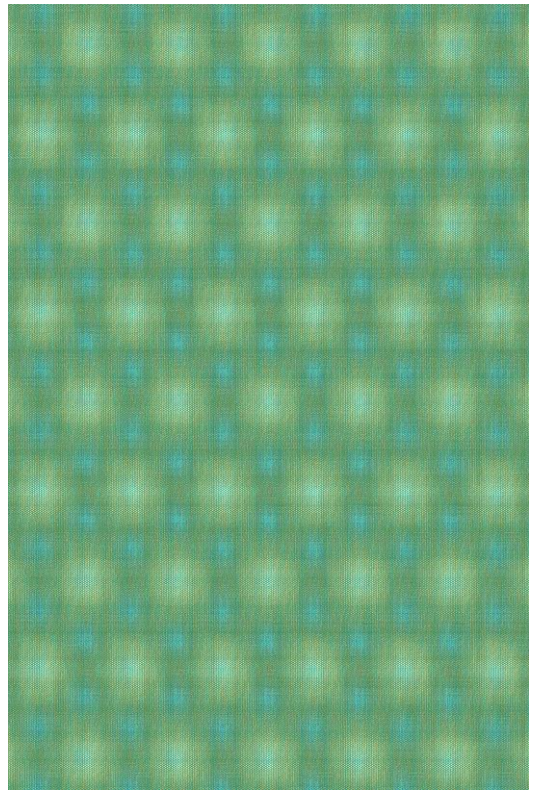


PFM moiré Confirmation





‘Super-moiré’ of Interest



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