PQS2D Annual Meeting 2026

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NSERC CRSNG
Fonds de recherche sur la nature et les technologies Québec
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Defect spectroscopy

McGill

Electrostatic forces in Atomic Force Microscopy

Electrostatic force between 2 capacitors is:

$$F_{El.static} = \frac{1}{2}\frac{\partial C}{\partial z}(V_{tip-sample} - V_{CPD})^2$$

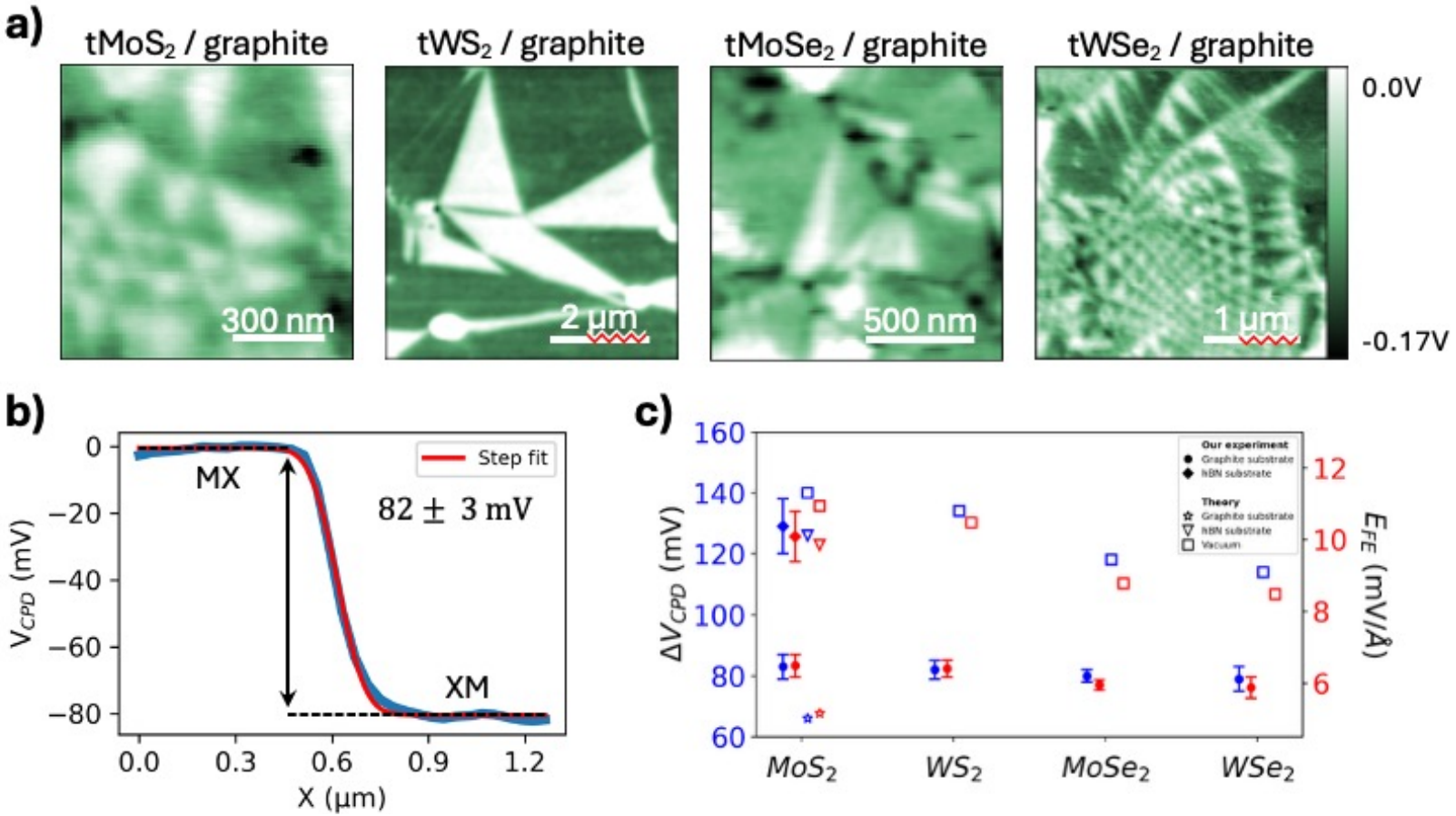
for conductive tip and sample!

$$V_{CPD} = [\Phi(\text{sample}) - \Phi(\text{tip})]/e$$

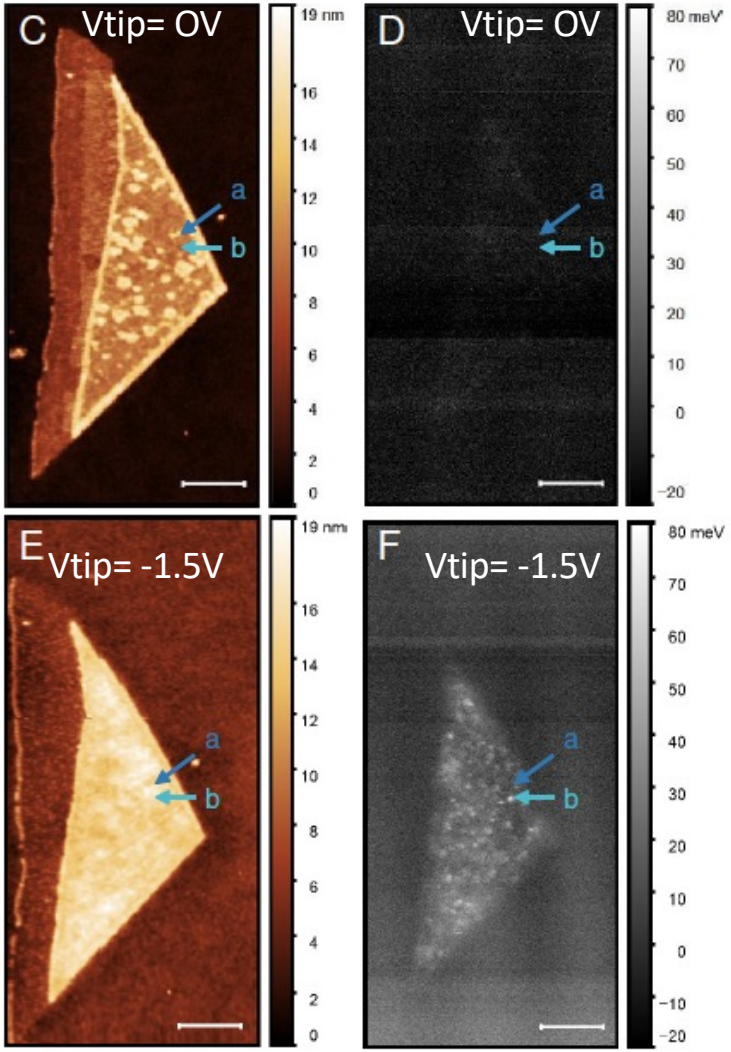
One can measure work function, surface potentials, charges, polarization, ….

Kelvin Probe Force Microscopy, Springer, ed. Sadewasser & Glatzel

KPFM measurements on samples prepared in Ottawa



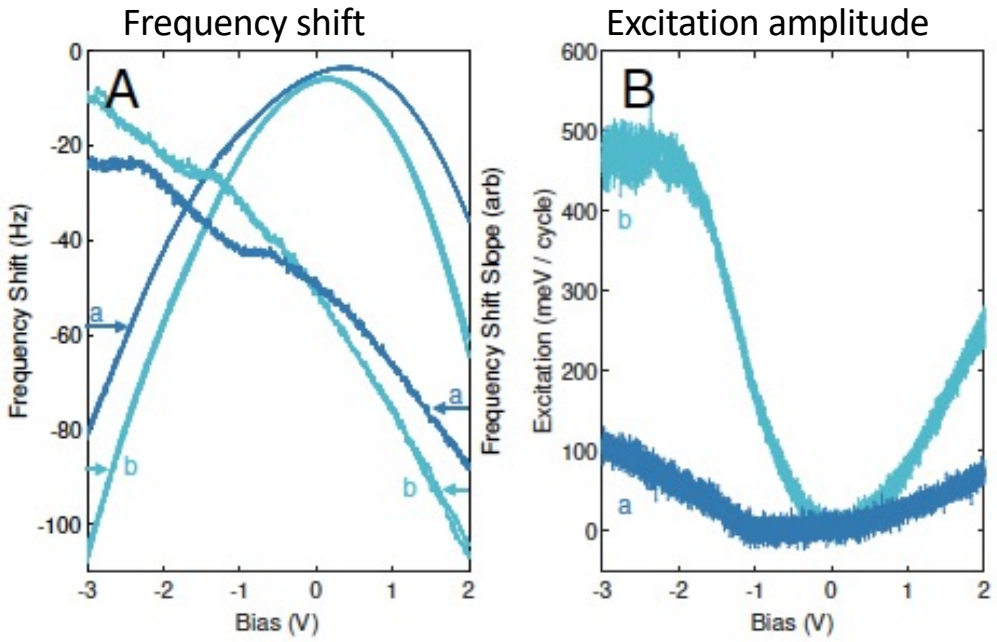
Jonathan Belise, Sean Chen, unpublished



Cowie et al., Phys. Rev. Materials **6**, 104002 (2022)

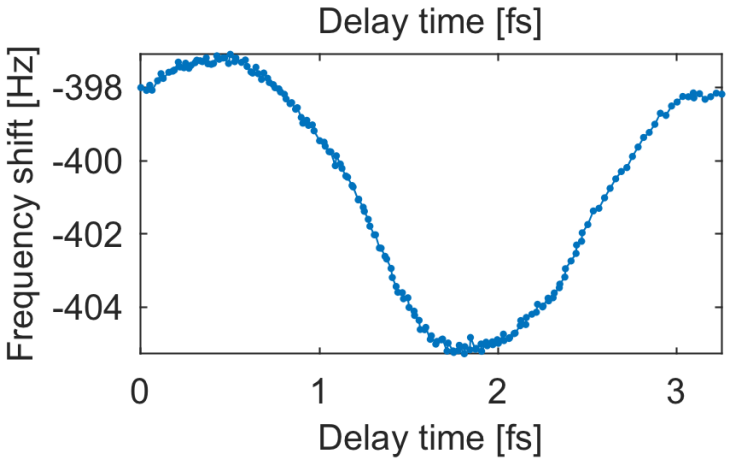
Apply MIS model to 2D $MoSe_2$

1. The band gap, dopant concentration, and susceptibility introduce nonparabolicity in Freq(V) spectra.
2. Charge reorganization time leads to structure in Exct(V) spectra

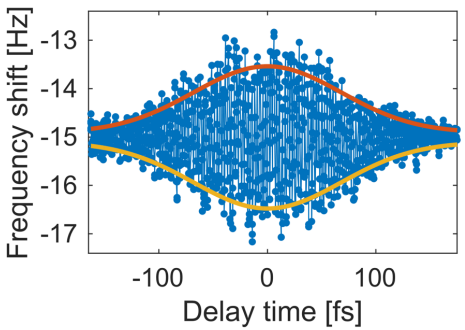


a = $MoSe_2$ b= defect

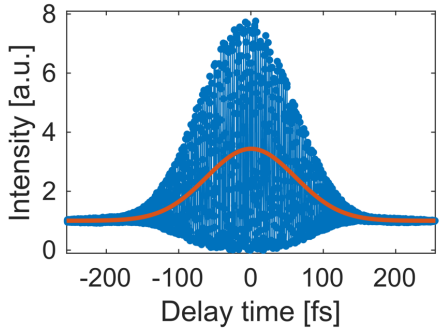
100fs optical pulse detected mechanically by AFM!



NC-AFM



Optical



~10 nm spatial resolution

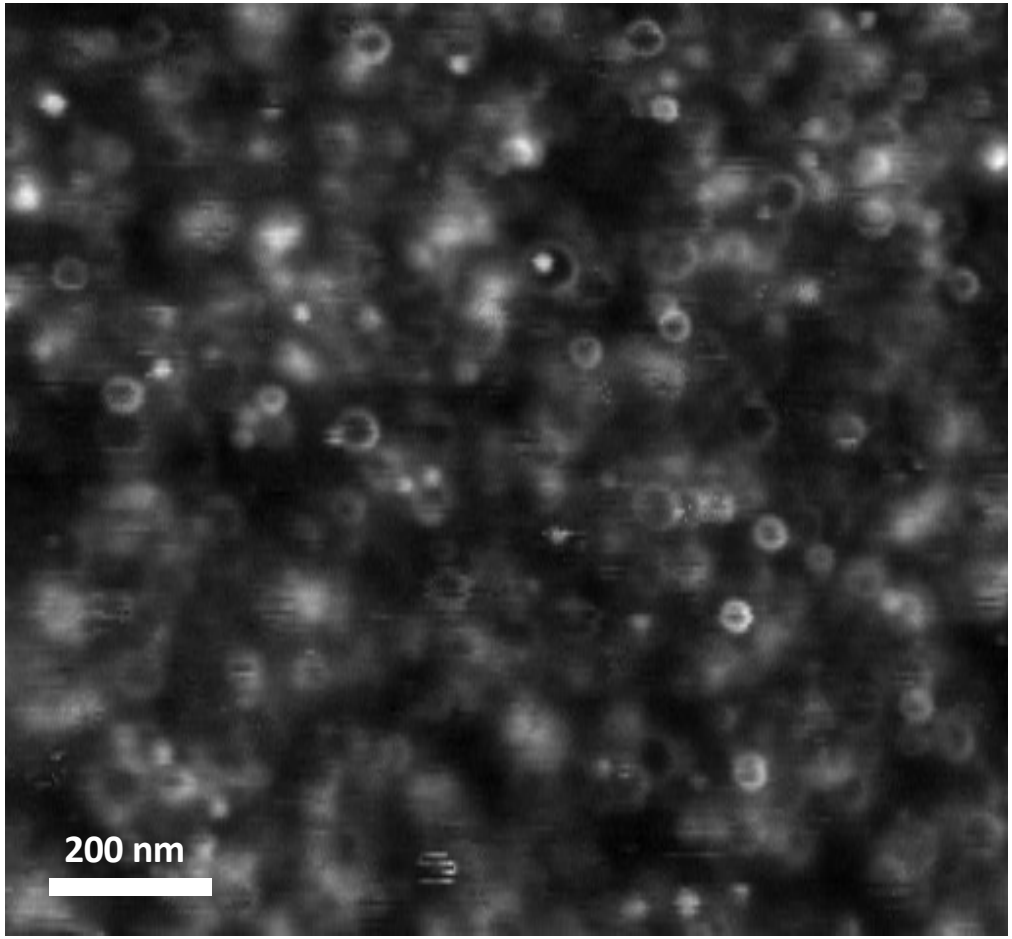
FWHM

AFM : 108.6 ± 3.8 fs

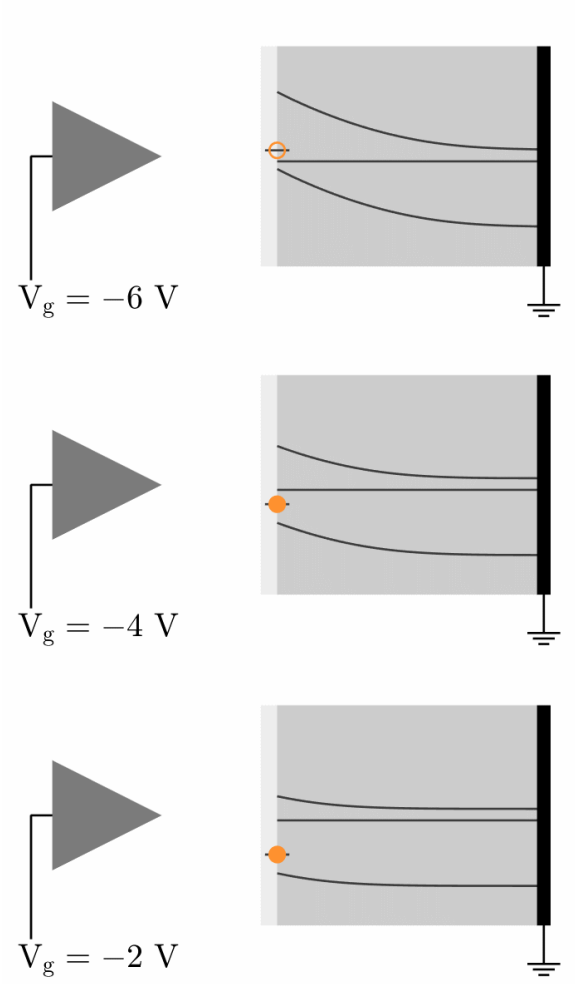
Optical: 106.5 ± 0.2 fs

Z. Schumacher, et al., *PNAS*. **117**, 19773 (2020)

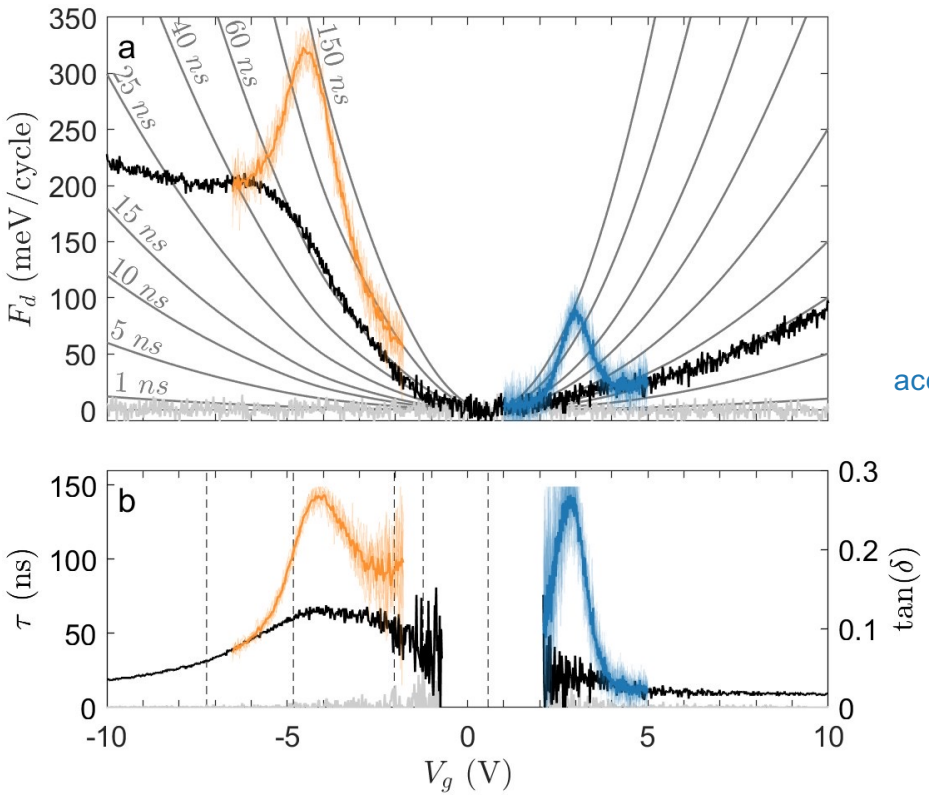
Interface traps at Si-SiO_2 interface



Single defect spectroscopy at Si-SiO_2 interface



Charge reorganization time is bias and location dependent



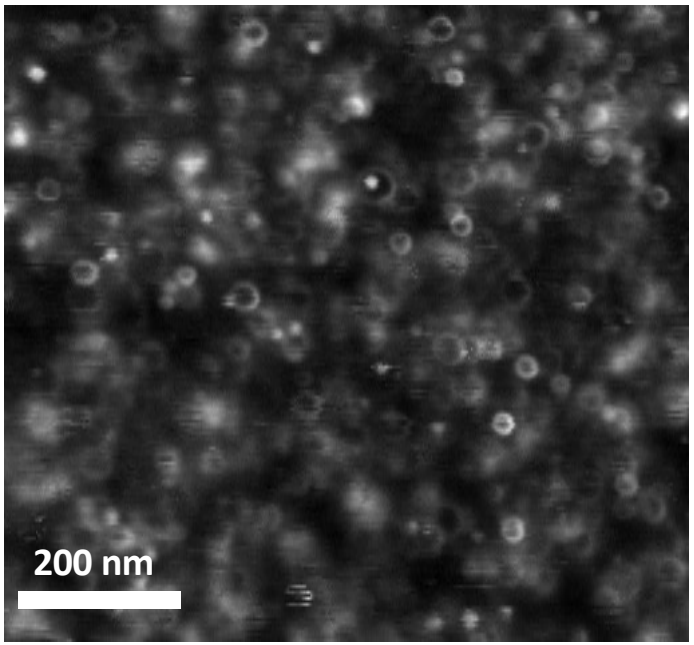
donor-like trap

acceptor-like trap

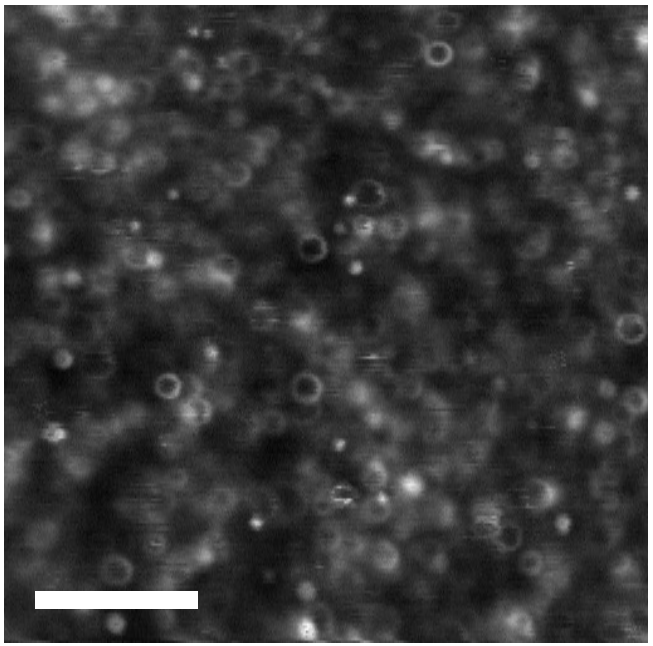
Cowie et al.,
Phys. Rev. Lett. **132**, 256202 (2024)

Interface trap density as a function of sample processing

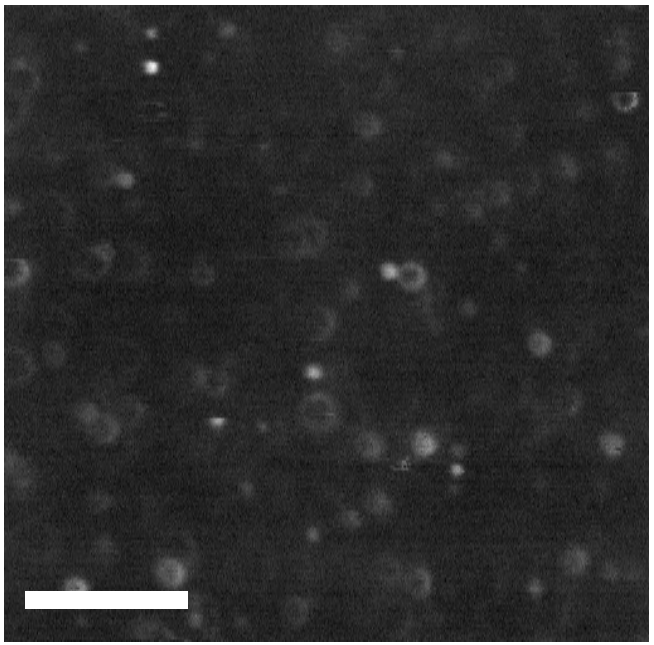
No Anneal



Annealed in N2 only

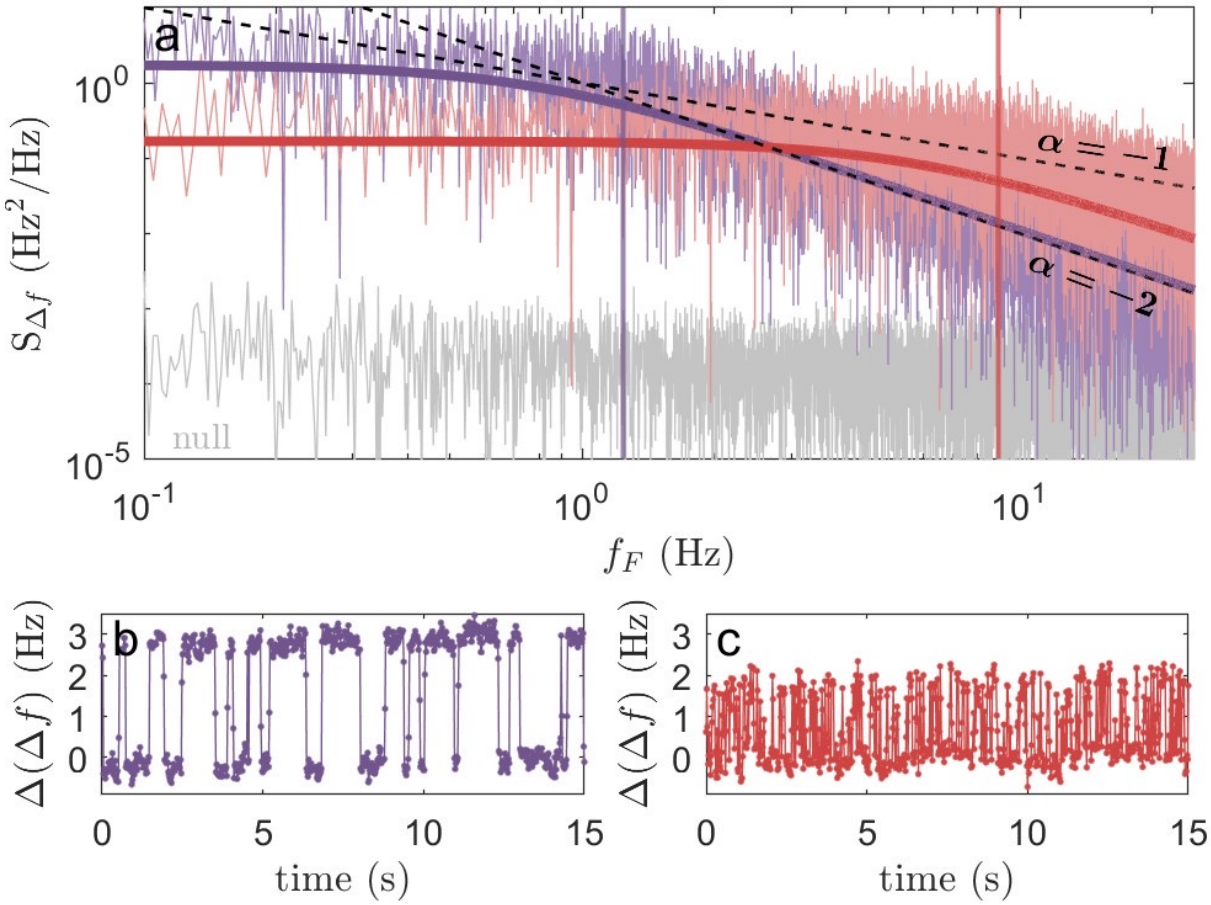


Annealed in N2 + H2



Czarnecki et al., AIP Advances **15,** 105024 (2025)

Ensemble of defects with different f_c lead to 1/f spectra



'slow' defect

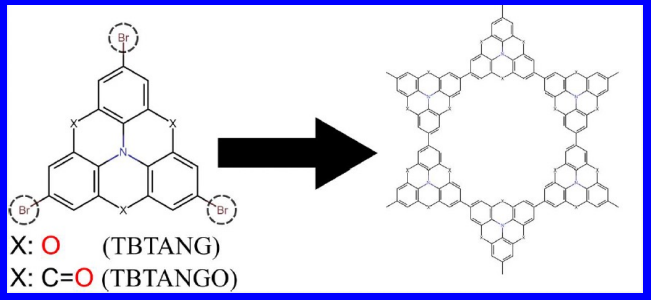
'fast' defect

Cowie et al., Proc. Natl. Acad. Sci. USA (2024)

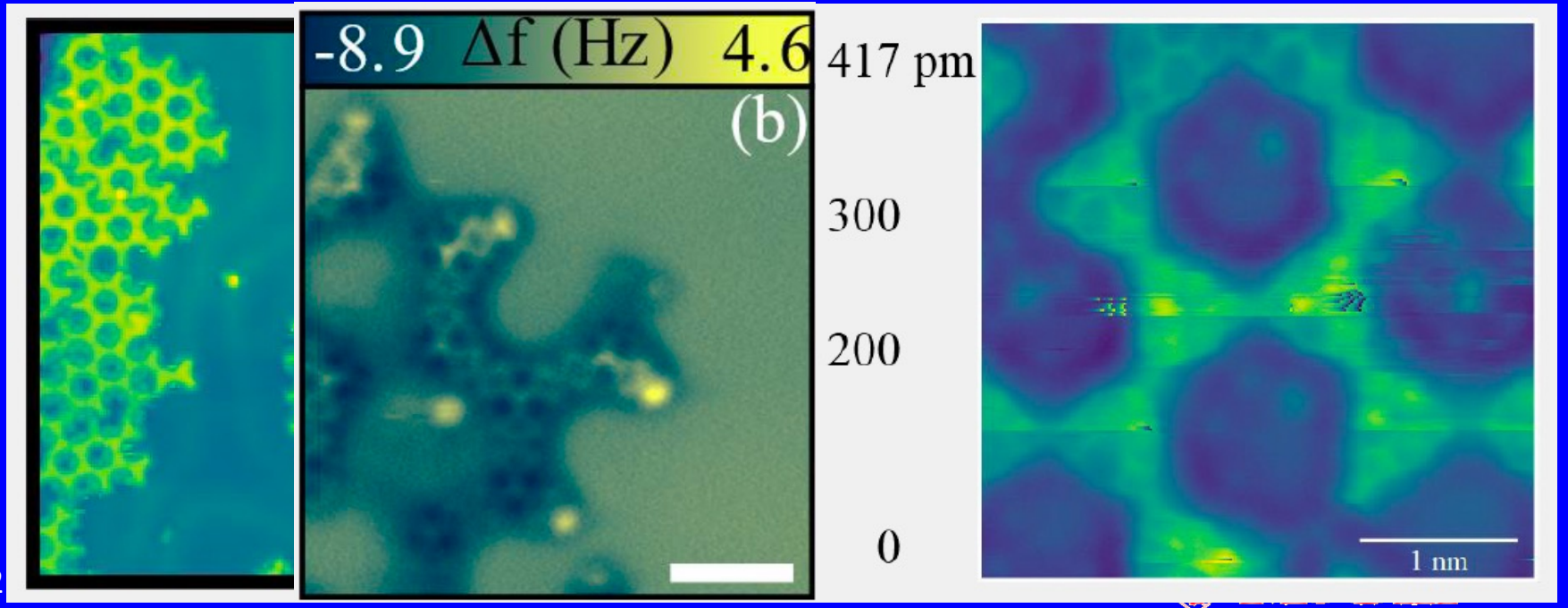
2D Kagomé lattice

Collaboration with
D. Perepichka,
Chem. McGill

On-surface reaction (Ullmann coupling) of azatriangulene derivatives with bridging groups:
oxygen = TBTANG
carbonyl = TBTANGO
→ **Forms Kagomé lattice with hexagonal pores**

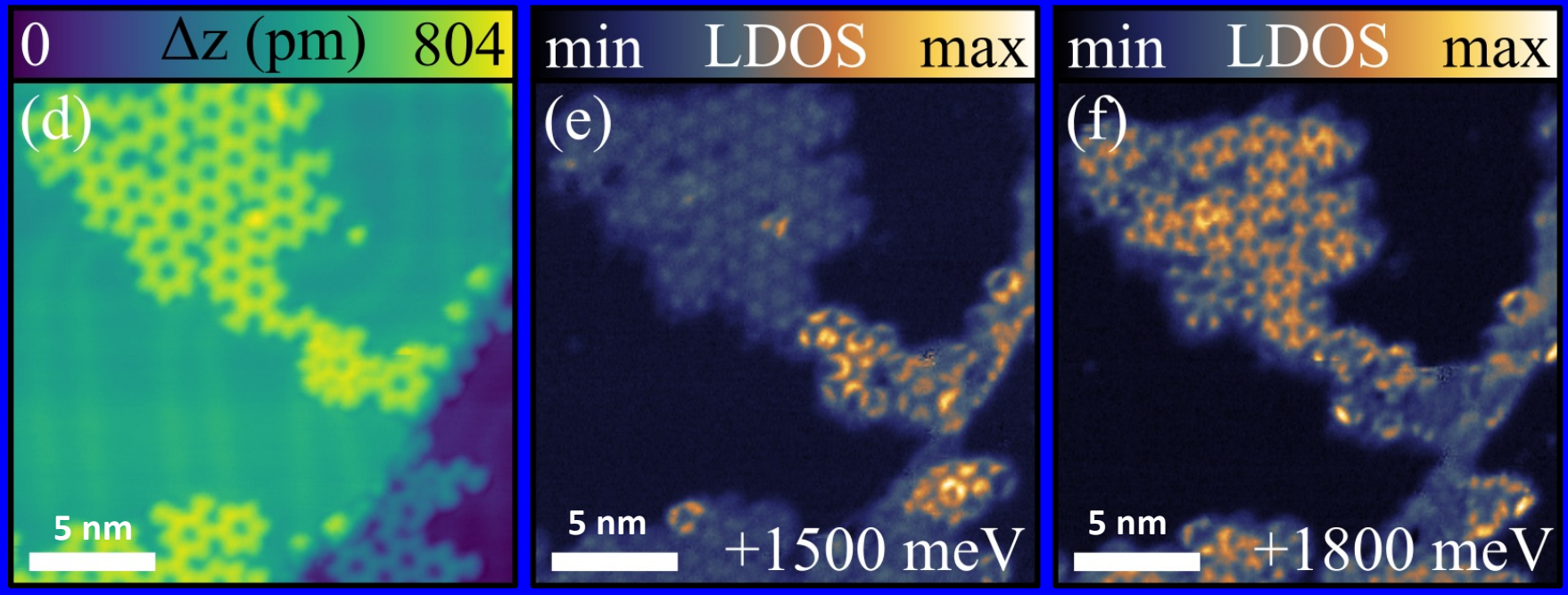


9K, UHV AFM



Subm. ACS Nano
arXiv:2606.27512

STM and STS of molecular pn-junction



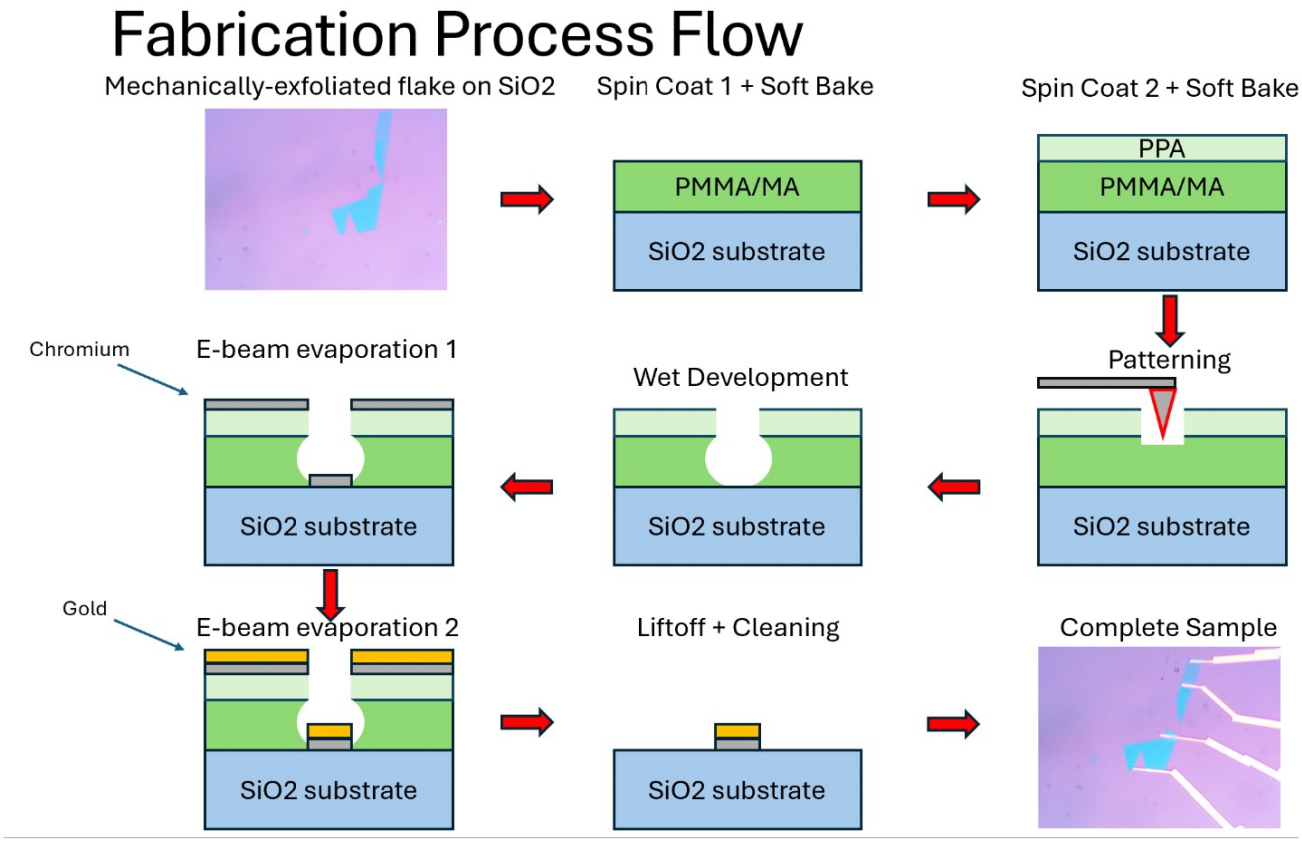
Sequential evaporation of TBTANG and TBTANGO, imaged at 9K, UHV

(Briesenick, unpublished)

Contacting 2D samples

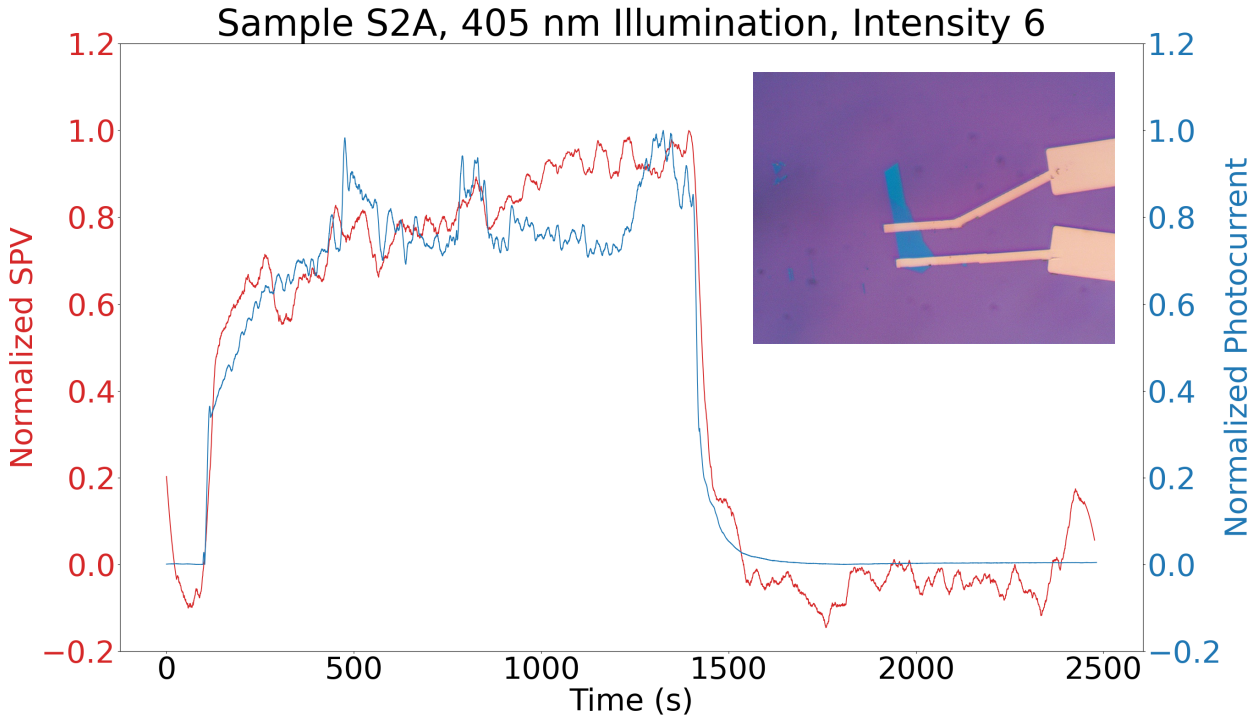
Lithography using either Nanofrazor Thermal Probe or UV Direct write laser

Supported by CMC/FaBrIC



M.Sc. Sean Chen

SPV and photocurrent WSe_2 (preliminary results)

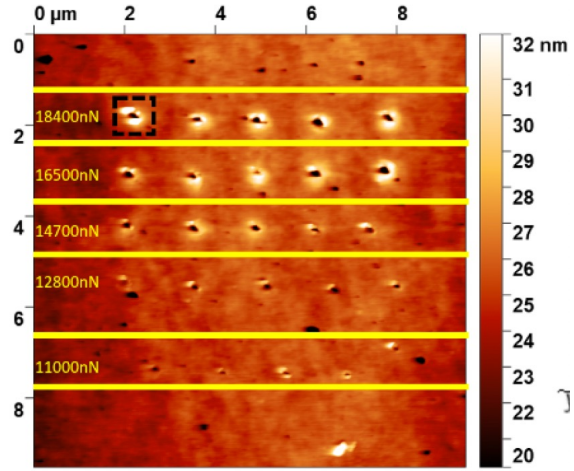


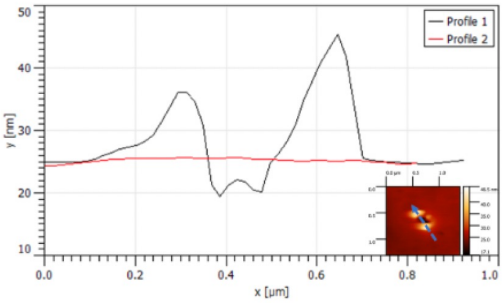
- Performed KPFM on thin exfoliated samples; response time varies a lot between samples.
- SPV and response times have thickness dependence
- Focus on slow-charging samples:
  SPV ~ 40mV
  PC ~ 300pA

Sean Chen, manuscript in prep.

Single photon sources in hBN via AFM nanoindentation

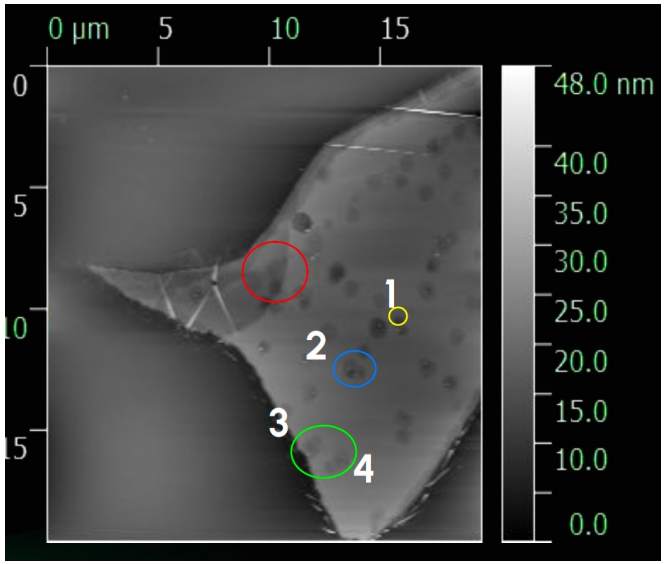
Nanoindentation tests

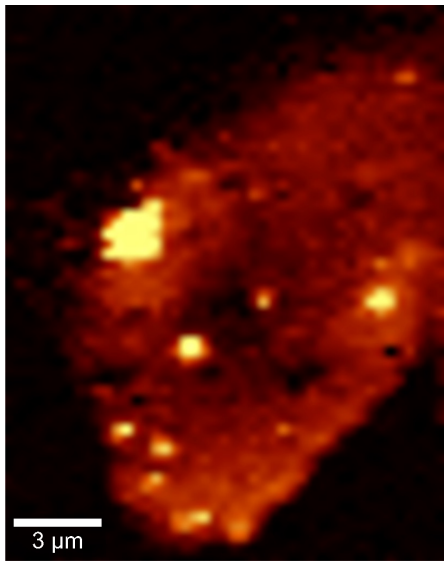




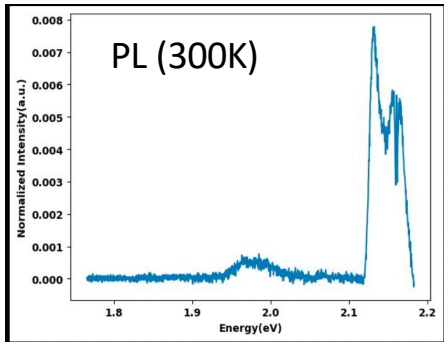
Shuhao Zhang PHYS 479 & summer 2024

Annealed (600K): some indents disappear





Label	Depth(nm)	Area(um^2)
1	5.7(2)	0.152(2)
2	7.2(1)	0.754(6)
3	5.08(7)	0.637(3)
4	4.20(2)	0.831(4)



Plan

- Properties of defects, including NLO on TMDs.
- Defect structures on hBN correlated with linear and non-linear optical properties (incl. electrical gating).
- Organic molecules in Moiré structures: structure and time resolved SVP (using viz-optical 100fs pulses).
- pn-junctions in Covalent Organic Frameworks, incl. spatially and time-resolved photoelectron decay (nm, 10fs).

Thank you for your attention – and thanks to my wonderful group of inspiring and talented students & PDF – past and present and future!



...and the Canadian tax payer for funding.

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