Few-Layer Transition Metal Dichalcogenide Exfoliation and Characterization for Future Electronics

Matei Jordache, Jierui Liang, Susan Fullerton

Department of Chemical and Petroleum Engineering, University of Pittsburgh

mcj21@pitt.edu

Goal

- Exfoliate and characterize monolayer transition metal dichalcogenide (TMD) flakes for use in memory devices

Motivation

- Thin TMD flakes exhibit unique electrical properties (high mobility, small band gap[1]) and mechanical properties (high flexibility[2])
- Attractive for construction of low-power, nanoscale devices and memory, requiring a reliable source of flakes for prototyping

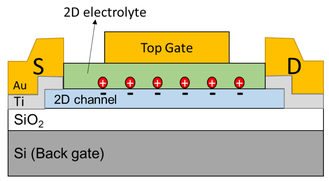


Fig. 1 Schematic of proposed device, using exfoliated MoS_2 as the 2D channel, CoCrPc as the electrolyte (green), and graphene as the top gate.

Exfoliation

- Mechanical exfoliation of thin flakes using the standard method, Figure 2.

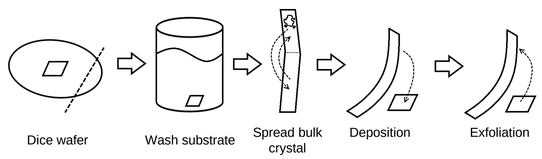


Fig. 2 Standard method for exfoliating thin flakes.

- Ideal flake for the channel is longer than 15µm and mono or bi-layer
- MoS_2 standard method yields poor results (2-3µm long, >5 layers thick)
- Experimenting with modifications to exfoliation process:
  - Thermal Annealing[3]
    - Anneal substrate for 5 minutes at 100° C prior to exfoliation
  - Reactive Ion Etching (RIE)[3]
    - Clean substrate with O_2 plasma prior to exfoliation
  - Varying levels of adhesive to perform exfoliation

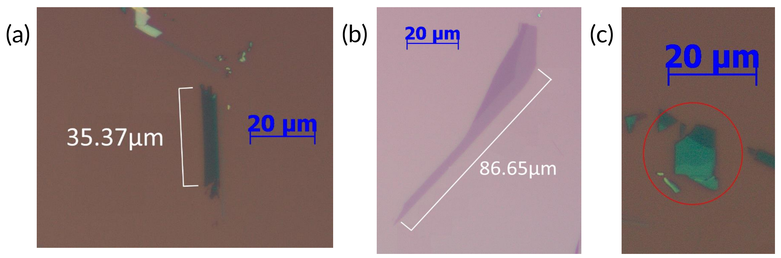
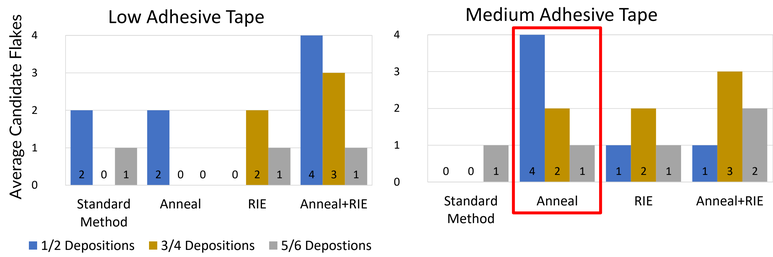


Fig. 3 Optical images of few-layer flakes. (a) Candidate MoS_2 flake exfoliated using thermal annealing . (b) Candidate graphene flake exfoliated using standard method. (c) An unusable MoS_2 flake (too thick).

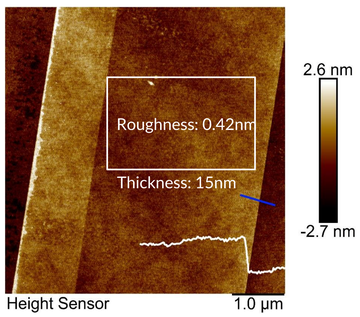
Alternate MoS_2 Exfoliation Method Results

- Annealing with the medium adhesive tape (Fig. 4b) and annealing + RIE with low adhesive tape (Fig 4a) gave the best results with 1/2 depositions
  - RIE is expensive, time-consuming
  - Annealing with 1/2 depositions using medium tape best option
  - High adhesive gave no results

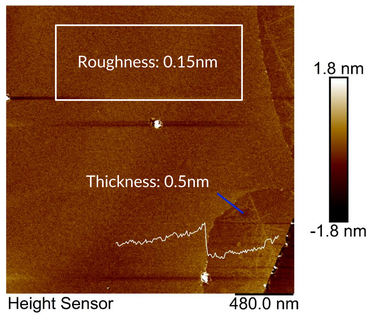


Characterization

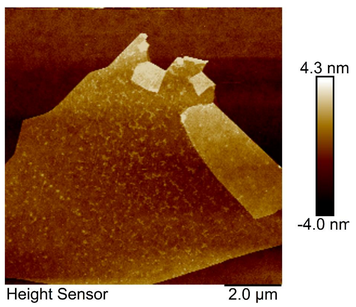
- After exfoliation, characterize the lateral size, thickness, and roughness of the flake using AFM:
  - If the flake is too small (< 10µm) it cannot be used in devices
  - Better exfoliation methods approach reliable monolayer flakes (~0.3nm for MoS_2)
  - The MoS_2 will get coated in 2D electrolyte (CoCRPc). The CoCRPc will not lie flat if the roughness is too high (R_Q > 1.5nm)



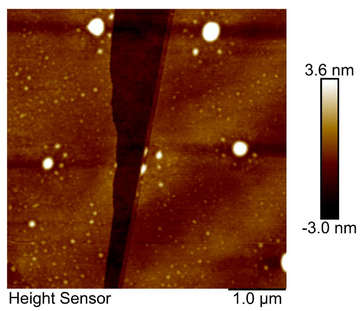
Step edge on uncoated MoS_2



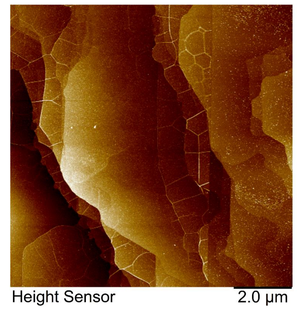
Step edge on CoCrPc coated MoS_2



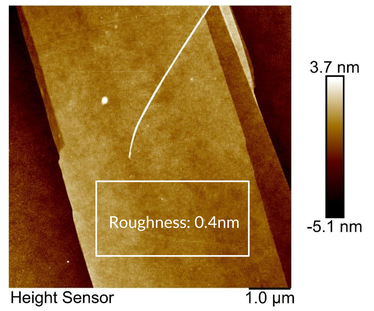
Bare boron nitride flake, used as an insulator for the device



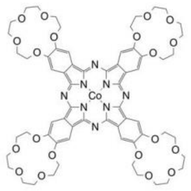
A crack and trapped debris or gas in a MoS_2 flake



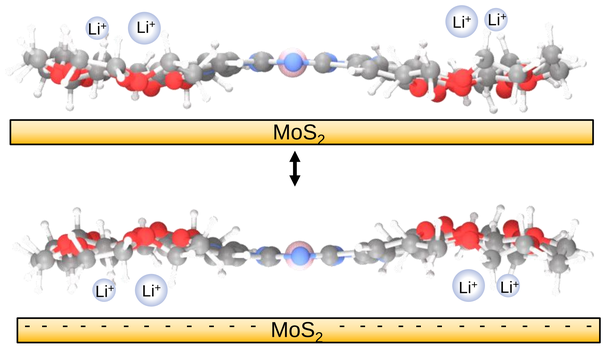
Expitaxial graphene with resist removed



Wrinkle formed in MoS_2 flake from exfoliation



- Cobalt Crown Ether Phthalocyanine (CoCrPc) is a novel 2D electrolyte
- Uses solvated Li^+ ions to reversibly dope the MoS_2 interface
- Electrolyte actuated by applying bias to the top gate
  - Bias released after state change



Conclusions and Future Work

1. Adding thermal annealing step during exfoliation yields reliable flake thickness and lateral size in MoS_2
2. Variation in exfoliation results between graphene and MoS_2 suggests different materials may need a different process or substrate.
3. Annealing does not leave any sticky residue from the tape on the flakes.

Future work:

- Explore use of other TMD materials like tungsten diselenide (WSe_2) and their exfoliation methods
- Use C-AFM to characterize electrical properties of flakes/coatings

References
[1] Radisavljevic, B., et al. *Nature nanotechnology* 6.3 (2011): 147-150.
[2] Fan, Z., et al. *Chin. Phys. B* 24.9 (2015): 097103-1-5
[3] Huang, Y., et al. *ACS nano* 9.11 (2015): 10613-10620
[4] Yun, W., et al. *Physical Review B* 85 (2012): 033305-2-4
[5] Lee, A., et al. *J. Phys.: Condens. Matter* 25 (2013): 082203-1-5
[6] Lee, A., et al. *Soft Matter* 9 (2013): 3762-3773

Acknowledgement:
This work was supported by NSF-ECCS/GOALI 1408425