Building a FET with 2D Transition Metal Dichalcogenides

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Outline

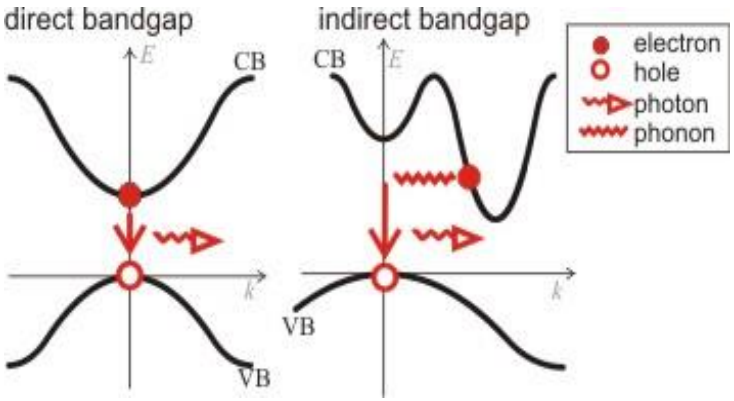
- Introduction
  - MX_2
  - Field Effect Transistors
- Methods
  - Spinning
  - Exfoliating
  - Searching
  - Transferring
- Future goals
- Conclusion

Delpierre, Sewell. *Electronic Science Tutor*. 2012. <http://www.physchem.co.za/data/periodic_table.htm>

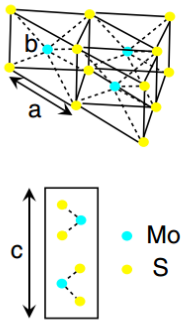
Transition Metal Dichalcogenides

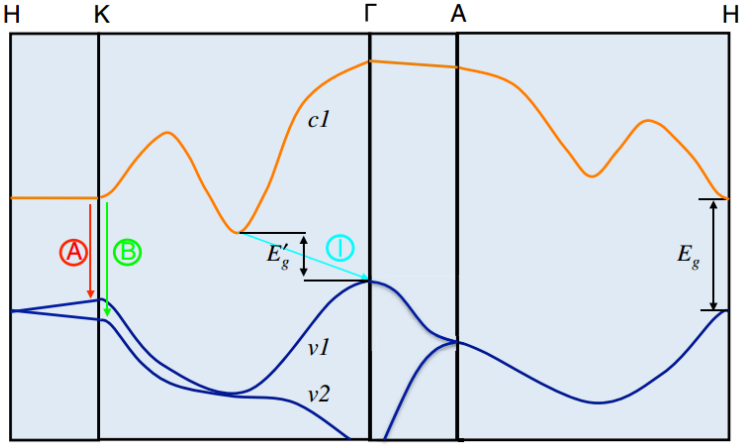
15	16	17
^{7}N	^{8}O	^{9}F
^{15}P	^{17}S	^{9}Cl
^{33}As	^{34}Se	^{35}Br
^{51}Sb	^{52}Te	^{53}I
^{83}Bi	^{84}Po	^{85}At
115	116	117

- Semiconductors following formula MX_2
  - M = W, Mo, Ti
  - X = S, Se, Te
- Changes to direct band gap material in limit of monolayer
  - Leads to improved optical properties compared to indirect band gap in bulk
- Lacks inversion center
  - New degree of freedom (k-valley index) applicable to valleytronics



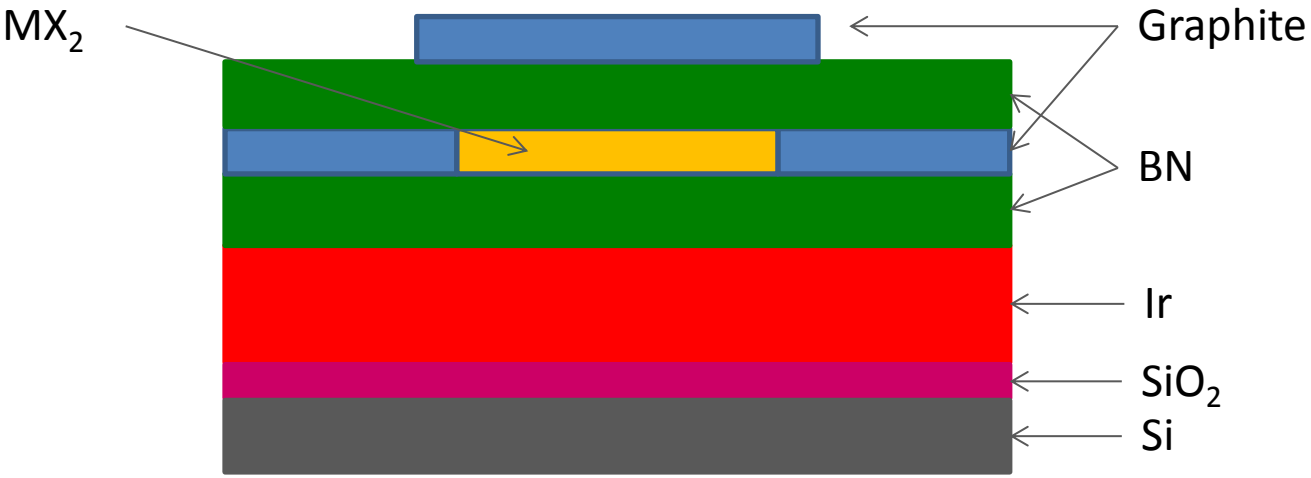
Pelant. *Nanocrystalline Silicon for Nanophotonics.* <http://nanotech.fzu.cz/26/index.php?file=4>





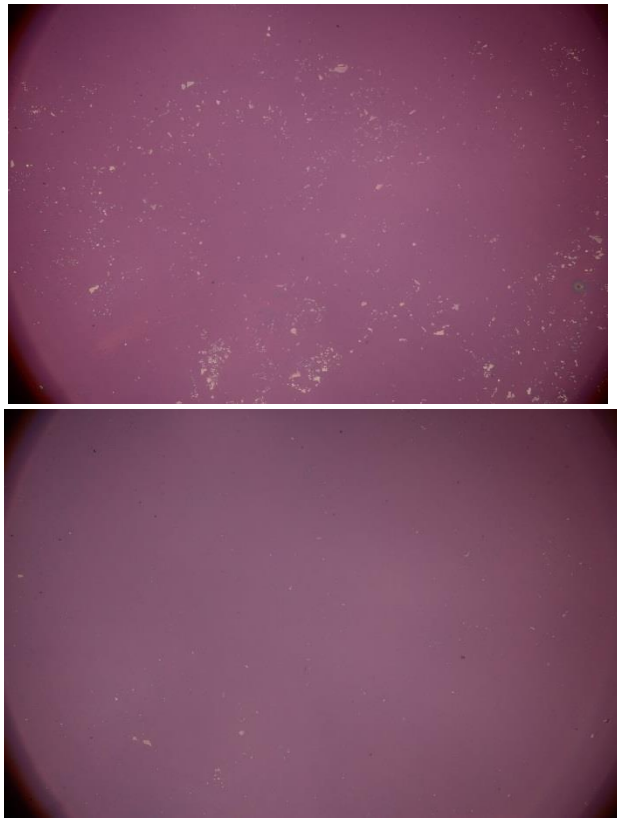
Mak, K.F., Lee, C., Hone, J., Shan, J., Heinz, T.F. "Atomically Thin MoS2: A New Direct-Gap Semiconductor." Physical Review Letters 105, 136805 (2010).

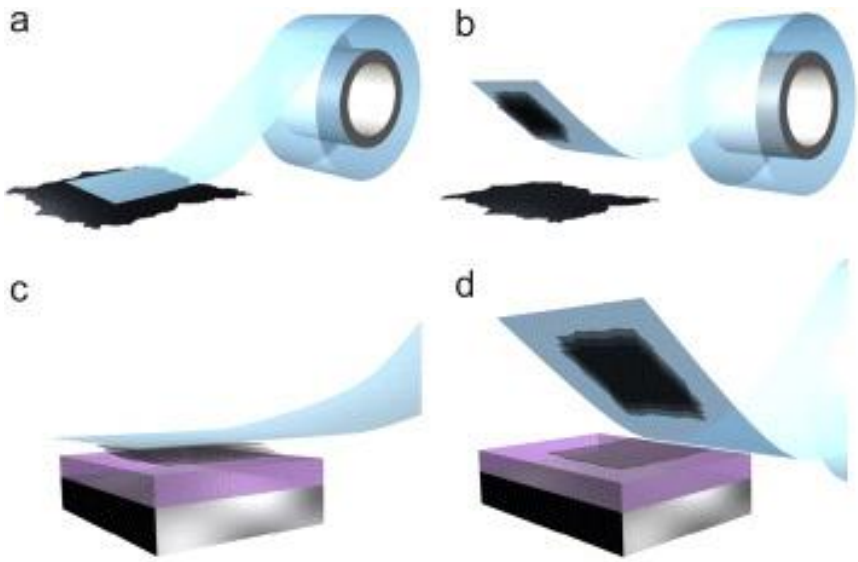
Our Field Effect Transistor



Spinning and Exfoliating

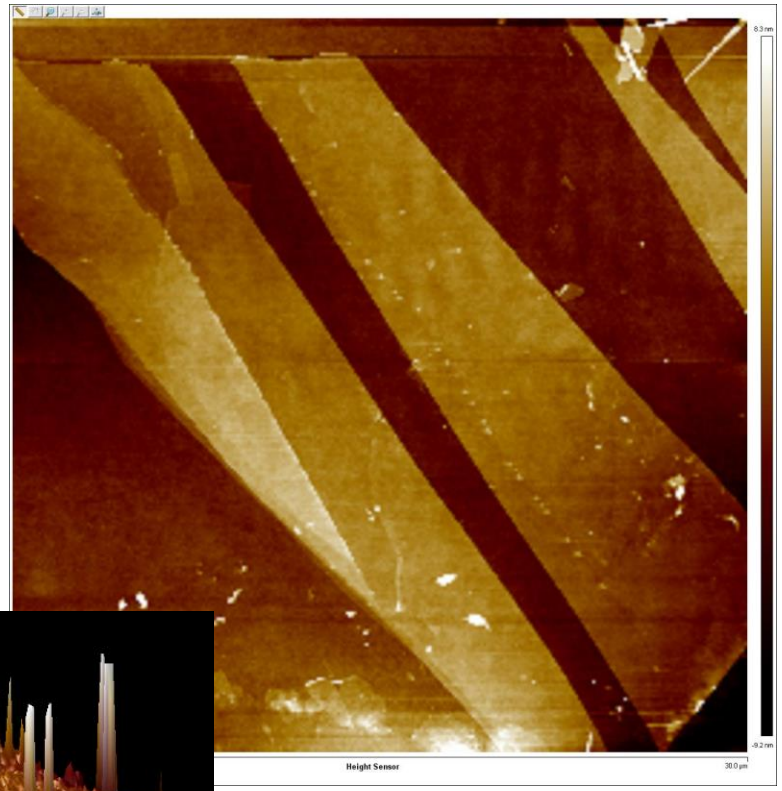
- Polyvinyl acetate(PVA) and polymethyl methacrylate (PMMA) spin-coated successively onto Si
- Mechanical exfoliation of graphite, boron nitride (BN), MX_2 onto PMMA

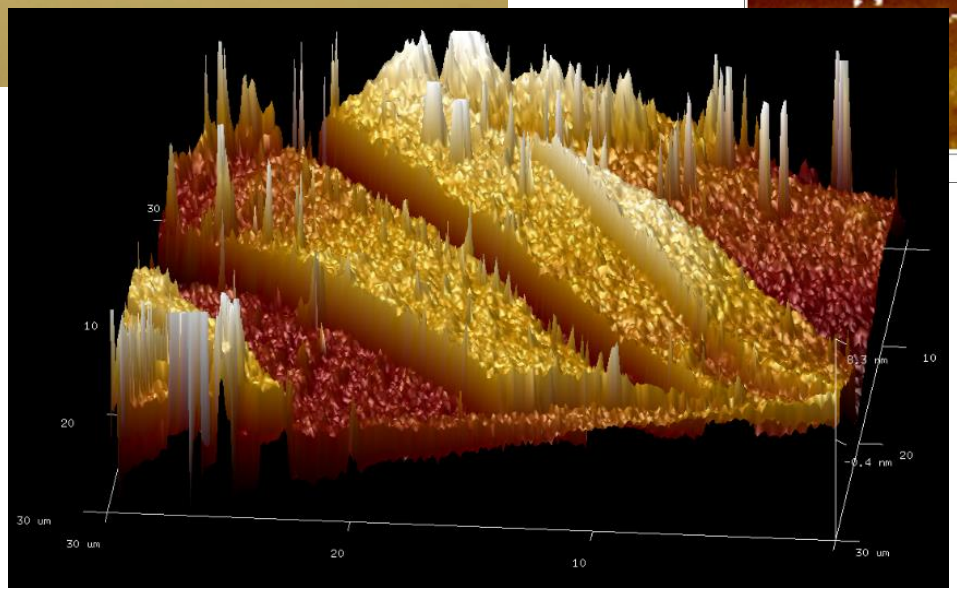




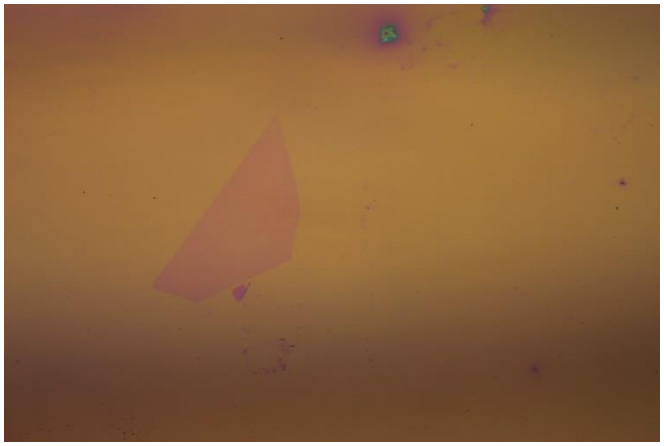
Novoselov, K. S., and A. H Castro Neto. "Two-dimensional Crystals-based Heterostructures: Materials with Tailored Properties." *Physica Scripta*T146 (2012): 014006. Web.

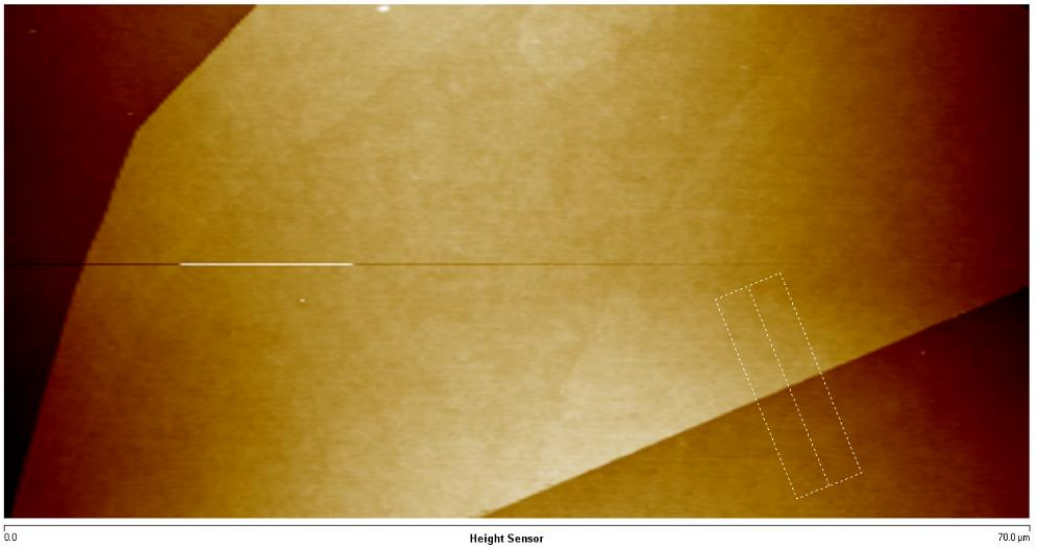
Graphite

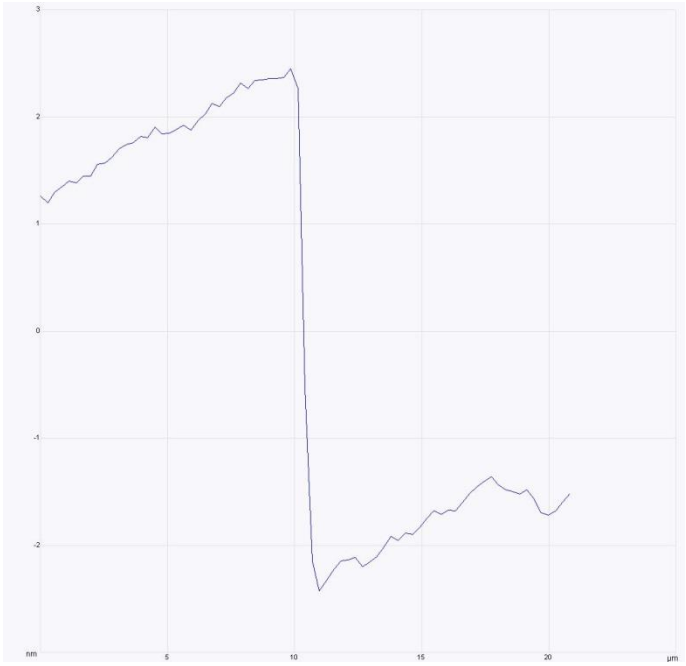


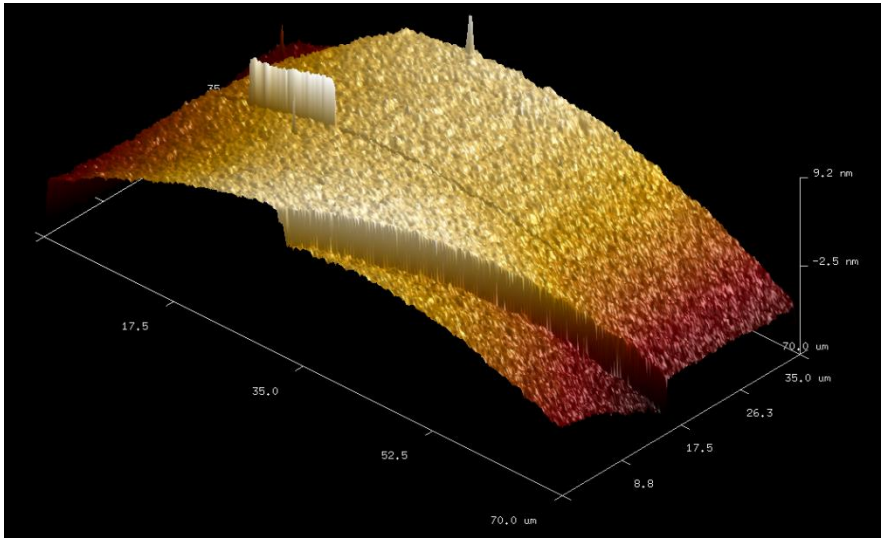


Boron Nitride

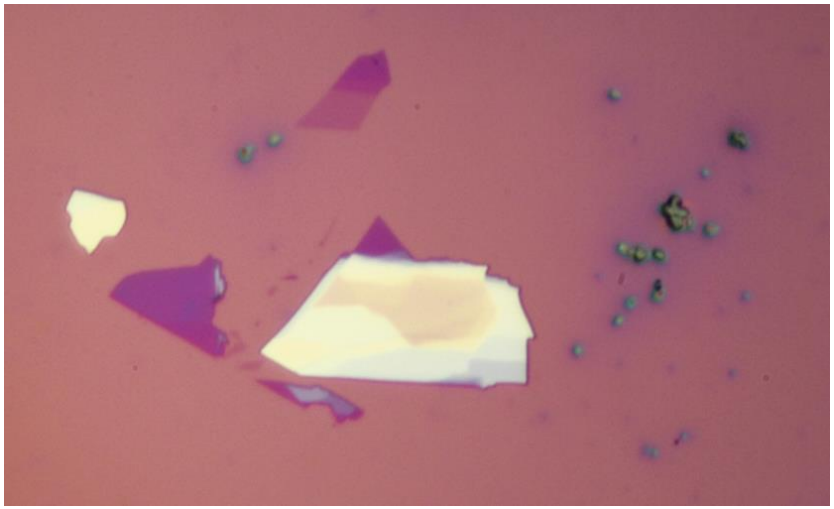


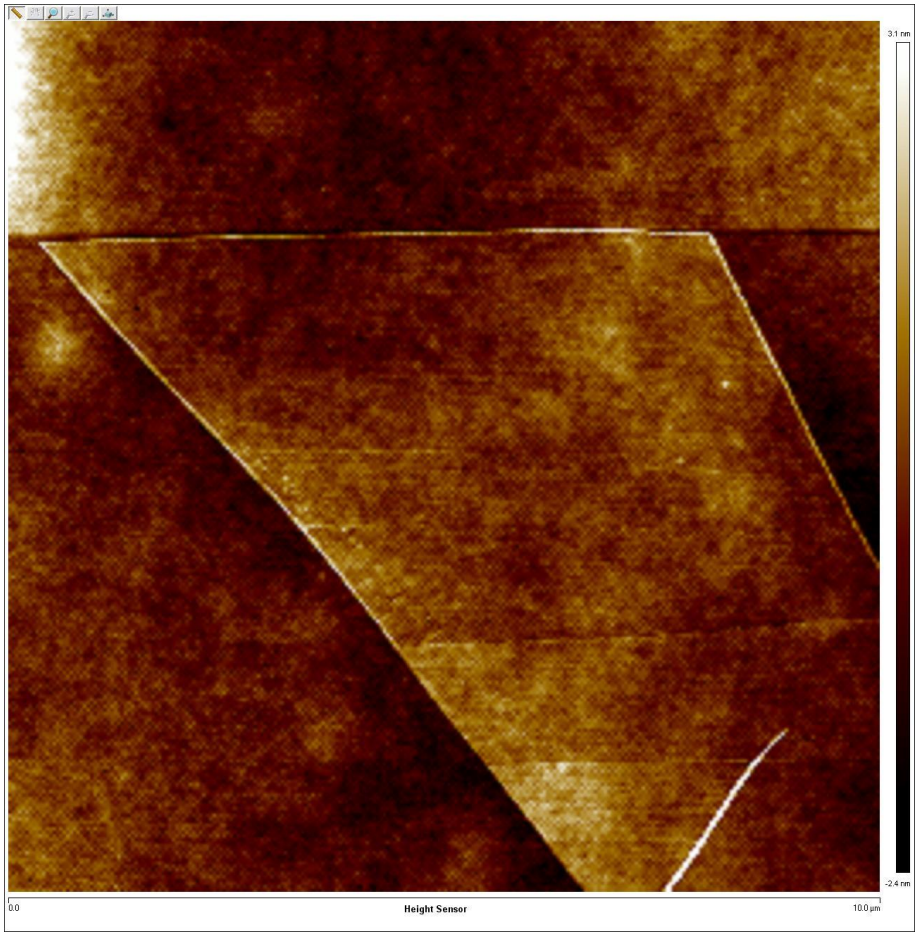






WSe_2

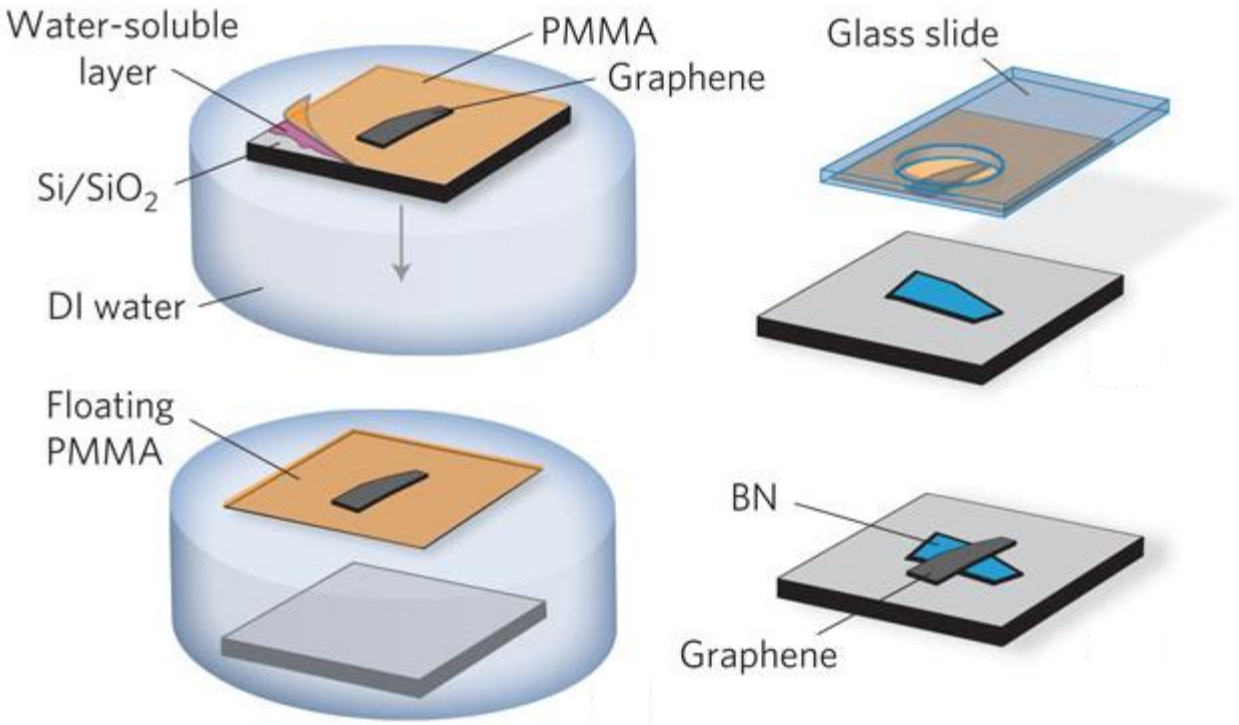




Transfer techniques

"Wet" Transfer

- Pro: Transfer is clean
- Con: Lacks accuracy, takes time

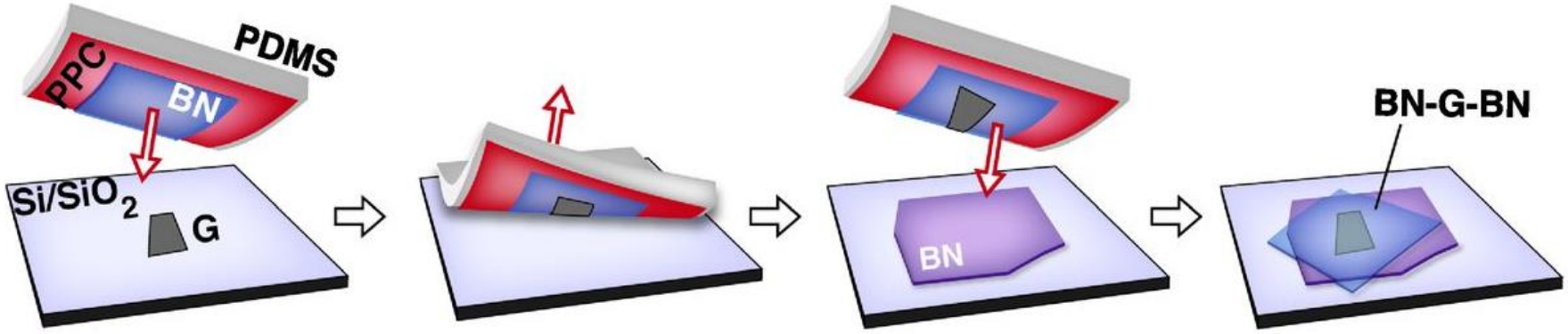


Dean, C. R., A. F. Young, I. Meric, C. Lee, L. Wang, S. Sorgenfrei, K. Watanabe, T. Taniguchi, P. Kim, K. L. Shepard, and J. Hone. "Boron Nitride Substrates for High-quality Graphene Electronics." *Nature Nanotechnology* 5.10 (2010): 722-26. Web.

Transfer techniques (cont.)

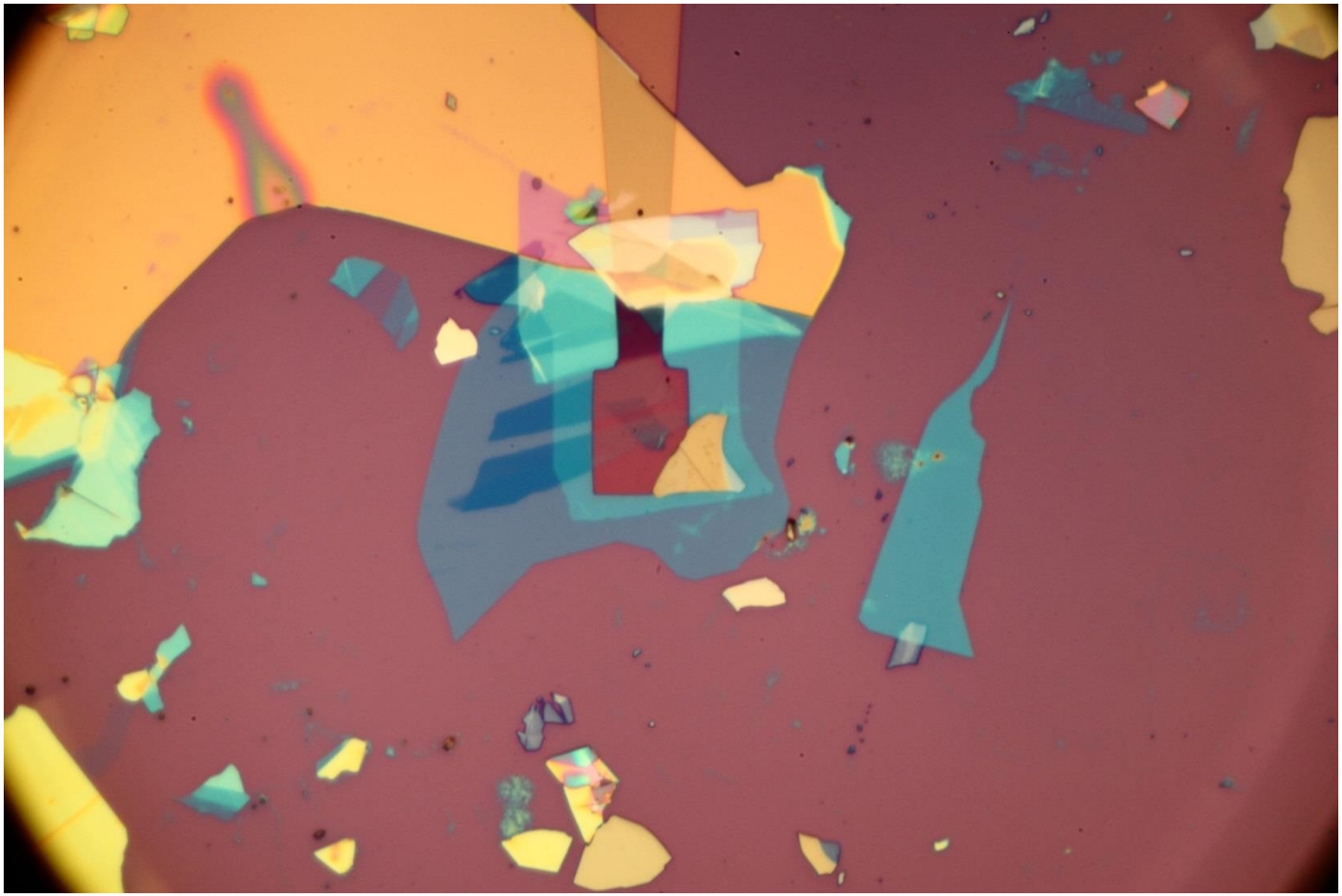
"Dry" Transfer

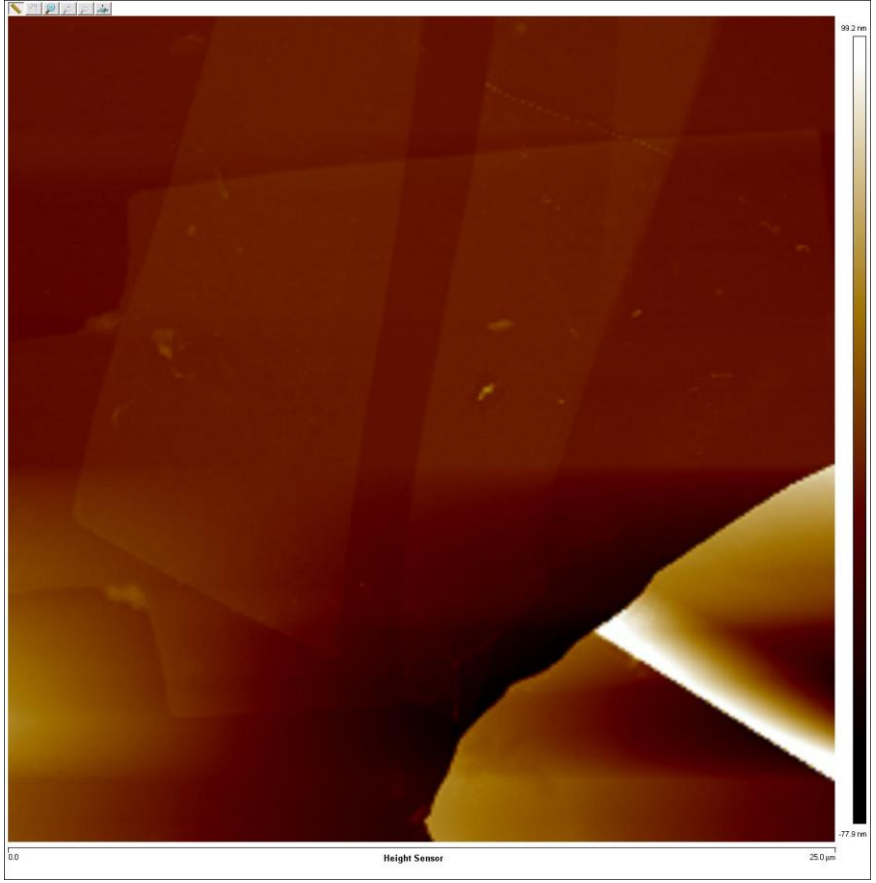
- Pro: Much easier to align, goes quicker
- Con: Pieces prone to folding, tearing, etc.

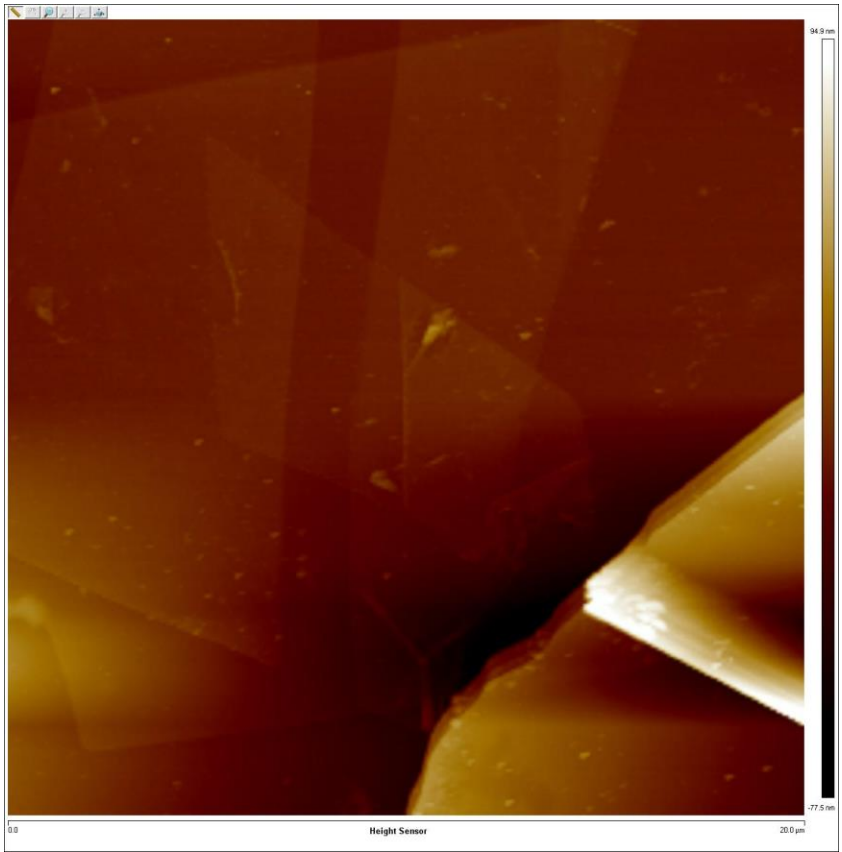


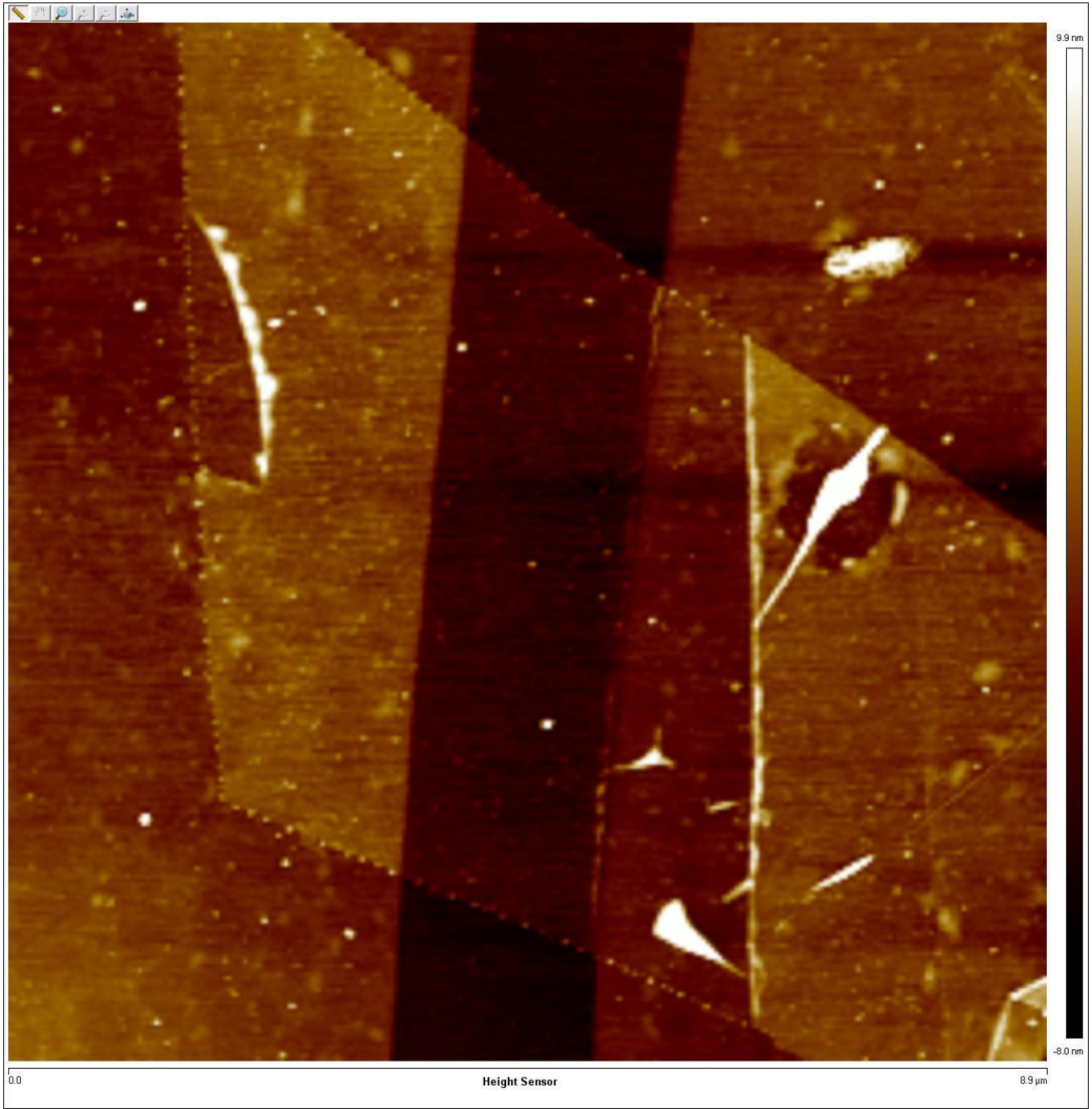
Wang, L., I. Meric, P. Y. Huang, Q. Gao, Y. Gao, H. Tran, T. Taniguchi, K. Watanabe, L. M. Campos, D. A. Muller, J. Guo, P. Kim, J. Hone, K. L. Shepard, and C. R. Dean. "One-Dimensional Electrical Contact to a Two-Dimensional Material." *Science* 342.6158 (2013): 614-17. Web.

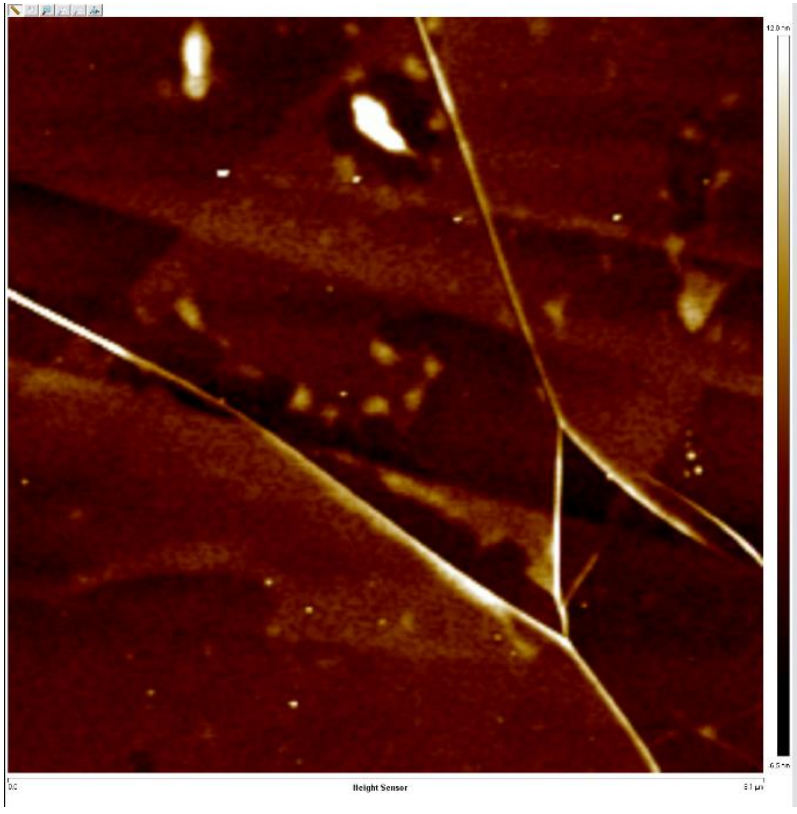
Example Device

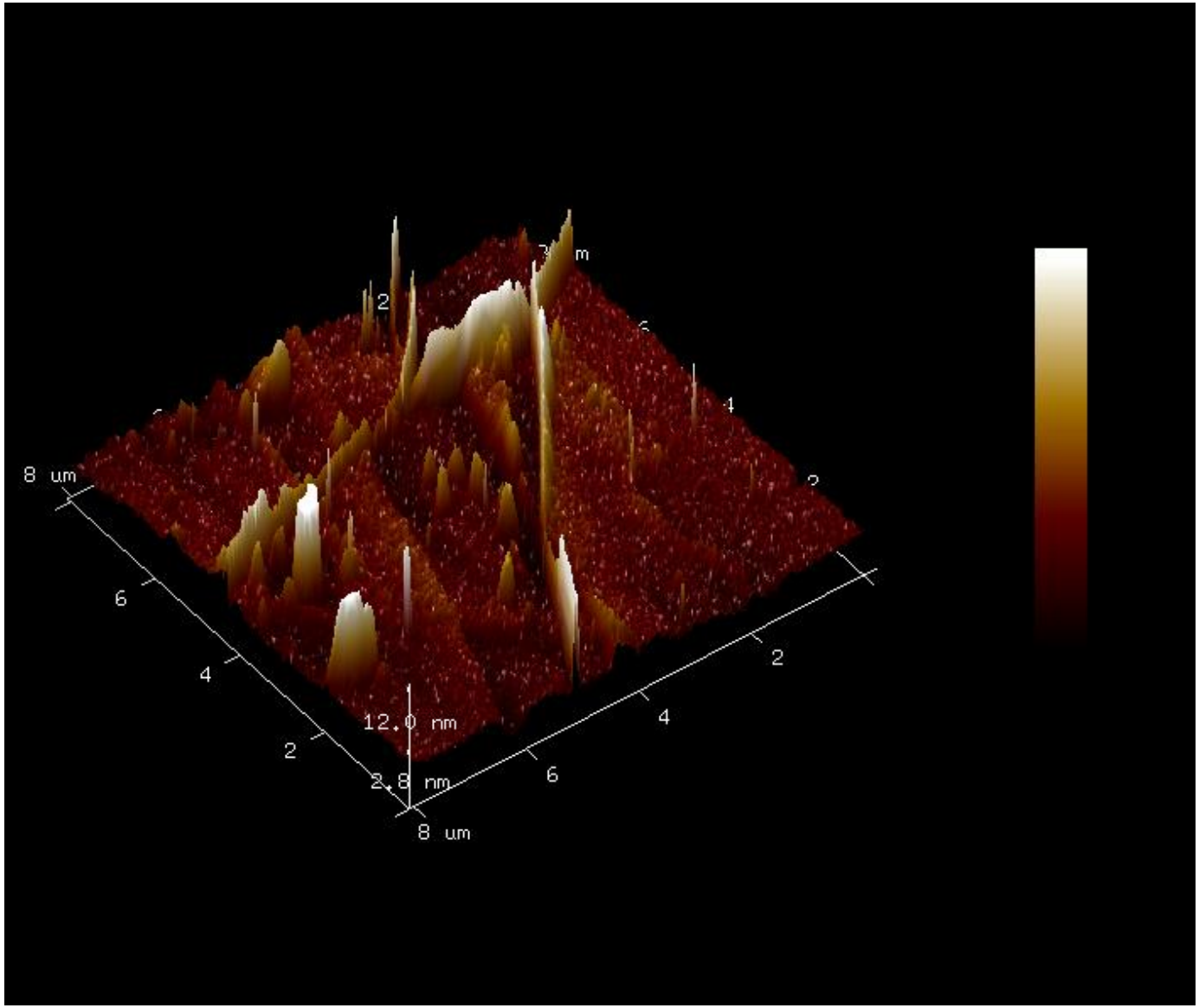



99.2 nm
-77.9 nm
0.0
Height Sensor
25.0 µm


94.9 nm
-77.5 nm
0.0
Height Sensor
20.0 µm


9.9 nm
-8.0 nm
0.0
Height Sensor
8.9 µm


Height Sensor


8 um
6
4
2
12.0 nm
2.8 nm
2
4
6
8 um

Future Goals

- Still a need for a viable transfer method
  - New method using polycarbonate (PC) spun on PDMS, then pick up flakes
- Once device completed, measure its various electronic properties (including carrier mobility and on/off ratio)
- Measure different Hall effects, including quantum spin Hall effect
  - Low temperature
  - Variable number of charge carriers

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