Graphene Auto-Kirigami: Forming 3D Structures Through Atomic Force Cutting

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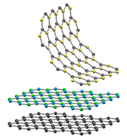
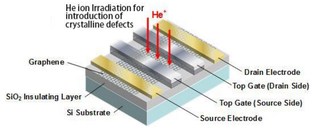
Introduction and Motivation

❑ 2D Materials

- 2D materials are structures with a thickness of a singular atom.
- These materials have remarkable mechanical, thermal, and electrical properties.



"Stacking 2D Materials," Churchhill Lab, http://churchill-lab.com/research

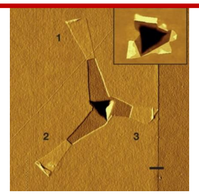


"Schematic Illustration of a Graphene Transistor Prototype," Phys.org, February 19, 2013, https://phys.org/news/2013-02-graphene-transistor-principle.html

- Graphene has an extremely high stiffness and is highly conductive.
- Possible applications in electrical components, optics, solar cells, etc.

❑ Auto-Kirigami

- Indentation or cutting can cause graphene to form 3D structures spontaneously; called Auto-Kirigami
- Controlling this phenomena could enable new nano-manufacturing methods for graphene components.



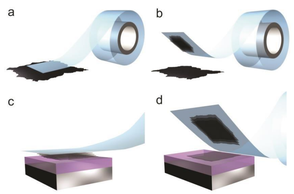
Annett, J., Cross, G. Self-assembly of graphene ribbons by spontaneous self-tearing and peeling from a substrate. *Nature* **535**, 271–275 (2016). https://doi.org/10.1038/nature18304

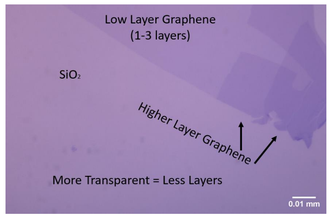
However, many of the parameters affecting Auto-Kirigami are not fully understood. Thus, a systematic exploration of these parameters and their effects is needed to harness Auto-Kirigami for future applications.

We seek to cut graphene while varying humidity and observe frictional changes as well as changes in Auto-Kirigami. Findings will allow us to further understand the phenomena and move us one step closer to manipulating and controlling the process.

Creating Graphene

- Graphite flakes are exfoliated with scotch tape and then are transferred to a clean SiO2 substrate and observed with optical microscopy. `

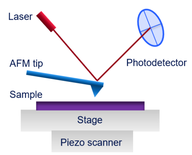




Freire Soler, Victor Manuel. (2014). Fabrication and Characterization of Macroscopic Graphene Layers on Metallic Substrates.

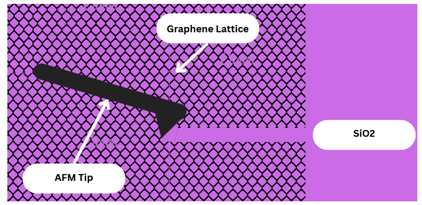
Atomic Force Microscopy

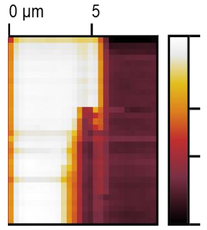
- Atomic Force Microscopy, or AFM, is how we image and cut samples
- In tapping mode, a tipped cantilever repeatedly taps the surface of the material, generating 3D plots of various measurements.



❑ Cutting Graphene

- In contact mode, the cantilever drags the tip along the surface of a material, generating friction plots simultaneously,



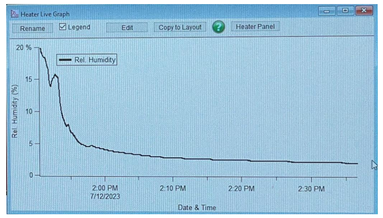


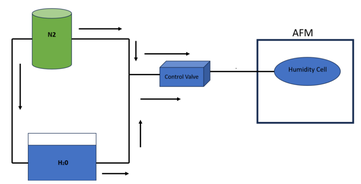
Low Friction

High Friction

❑ Varying Humidity

- Humidity is varied by feeding N_2 and Water Vapor into a humidity cell and stabilizing the RH at a specific level.

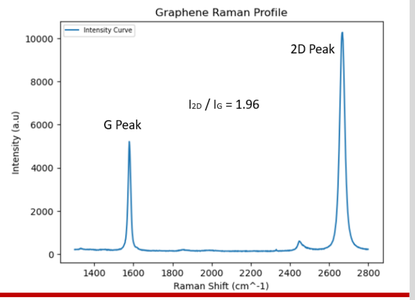




Results

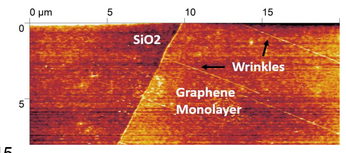
○ Determining Layer Number

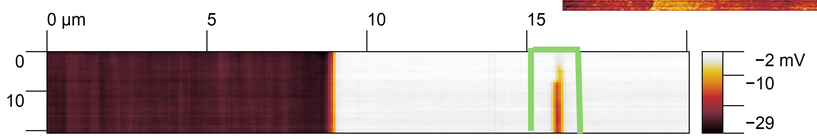
- We can use Raman Spectroscopy and take the ratio of Graphene's 2D and G peaks to determine the layer number.
  - I2D / IG ratios of ~2 confirm that the sample is a monolayer.



○ Friction Measurements

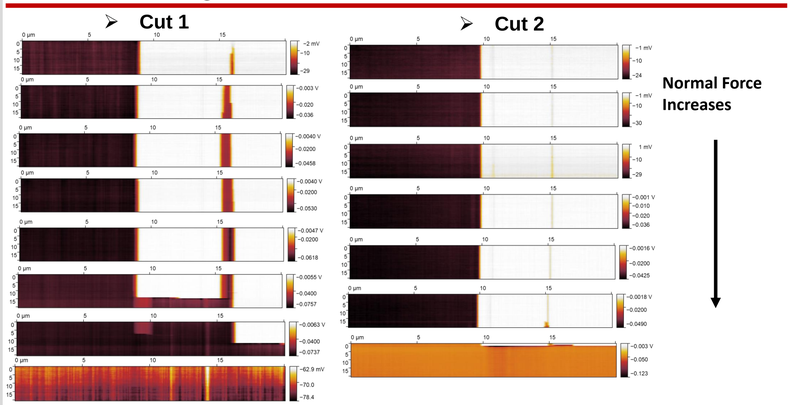
- Fracture will begin at defect points along the surface of the material, such as a wrinkle.





- The highlighted portion of the friction measurement corresponds to where a wrinkle intersected with the cutting line.

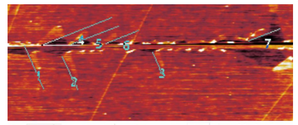
❑ Friction Progression



- We can observe how the friction changes over time as we increase the force applied by our AFM Tip.
- We can see fracture happens at similar forces but takes different paths to reach there.

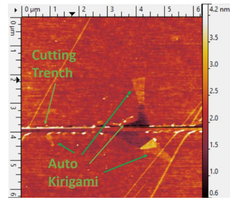
❑ Auto-Kirigami

- We have observed similar final tear and twist angle among single rip Auto-Kirigami and is likely a result of the lattice orientation of the graphene.
- This cut was made at low Relative Humidity (RH) (1-2%).



n	φ [deg]
1	-65.8
2	-64.7
3	-65.9

n	φ [deg]
4	21.3
5	20.6
6	21.5
7	20.7



Conclusions

- We have developed a consistent method to cut graphene as well as record frictional data to obtain data at the point of fracture.
- We have identified points of interest in Auto-Kirigami which will give direction for structing experiments in the future.
- Not enough data has been taken, and so more cuts are needed. `

Future Research

- Create more cuts and gather data at all levels of humidity, especially those in the 75-85% RH range.
- Further investigate similar angle tears at low humidity.
- Use Raman Spectroscopy to identify twist angles amongst folded layers

Acknowledgements

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