

Wyatt Jebef^{1,2}, Zafer Mutlu², and Jeffrey Bokor²
¹Santa Barbara City College, ²EECS Department, University of California, Berkeley

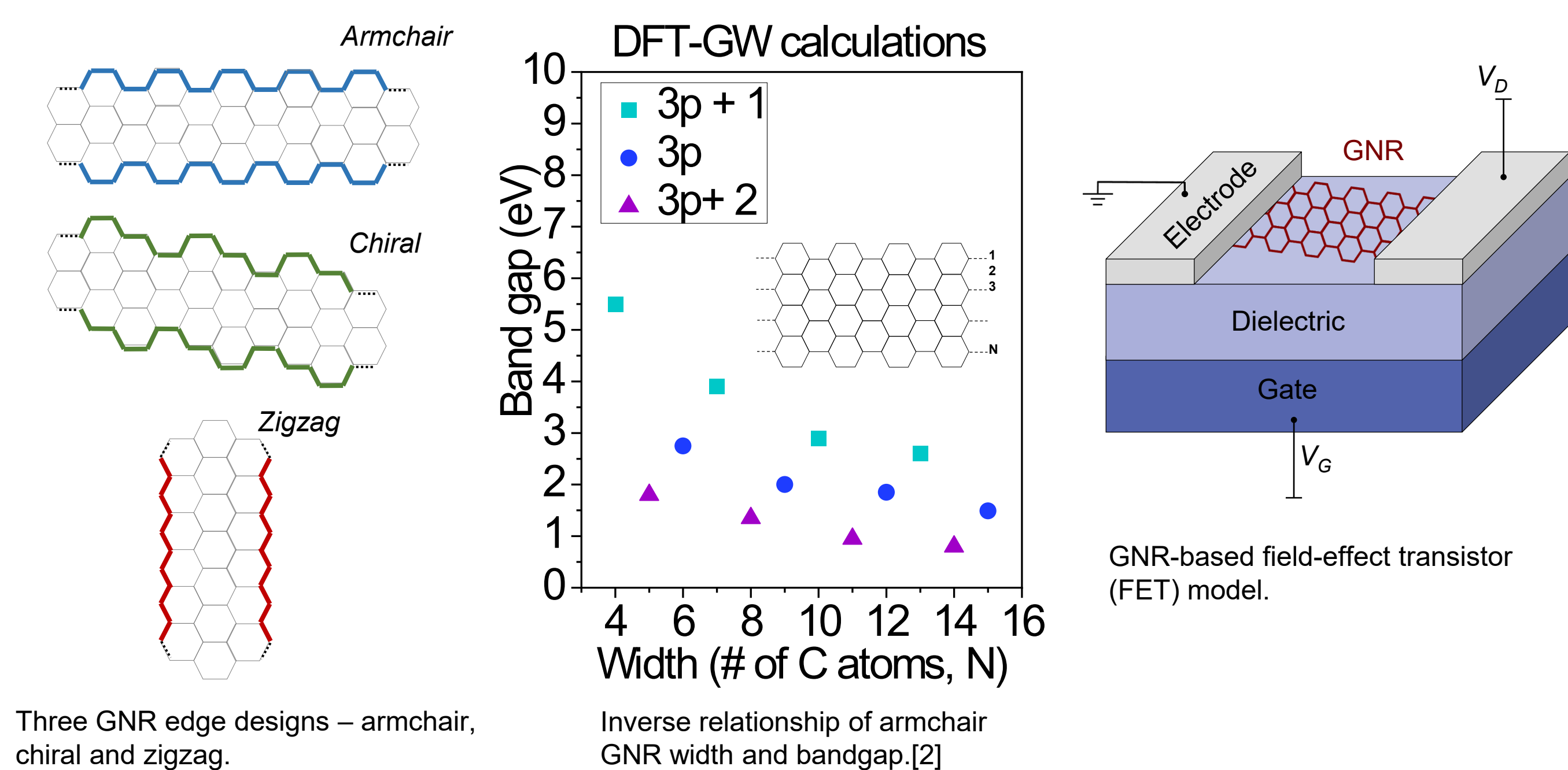
2020 Transfer-to-Excellence Research Experiences for Undergraduates Program (TTE REU Program)

Abstract

Graphene nanoribbons (GNRs) are quasi-one-dimensional carbon-based semiconductors that possess a tunable bandgap contingent on ribbon width and edge topology and are therefore a promising alternative for silicon channels in future transistors. The bottom-up synthesis of GNRs provides ultimate control over ribbon design and thus their electronic properties. STM and Raman spectroscopy are the two standard techniques used for characterizing bottom-up synthesized GNRs. Although STM is an effective method to obtain atomic-scale information, its scope is localized and is limited to GNR samples grown on metallic substrates. Contrastingly, Raman spectroscopy is a fast and non-invasive analytical approach that provides complementary information about GNRs on both metallic and insulating substrates at a macroscopic scale. However, most contemporary studies only use Raman spectroscopy to identify GNR type. Herein, we investigate the effect of growth substrates, doping and the transfer process on the Raman features of seven-atom wide armchair GNRs (7-AGNRs) in order to advance their large-scale characterization and implementation in transistors.

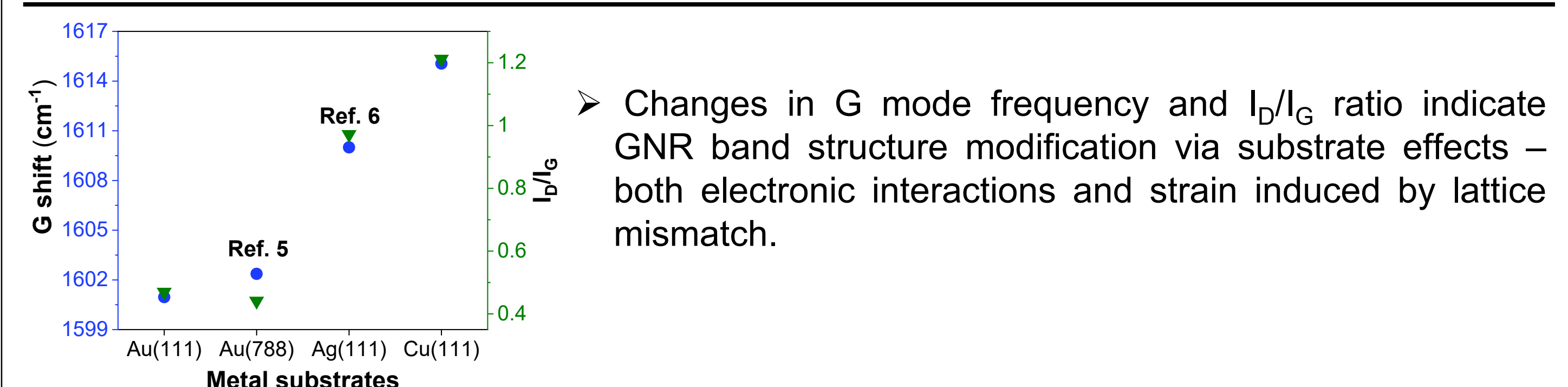
Motivation

- Bottom-up synthesis enables GNR bandgap engineering via molecular precursor design and produces uniform GNRs that can serve as key elements for post-silicon CMOS devices.[1]
- ✓ **Project goal:** Increase current understanding of GNR Raman modes to advance the large-scale ex-situ characterization of GNRs and improve device fabrication techniques.
- **Long-term goal:** Implement GNRs in high-performance transistors.

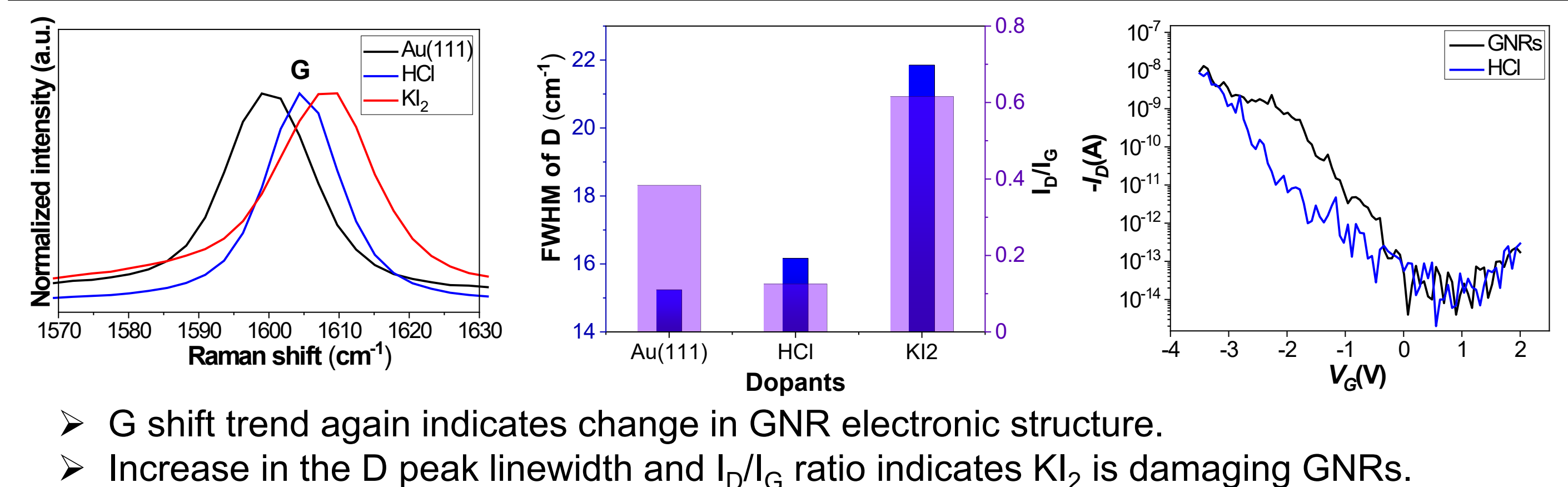


Results

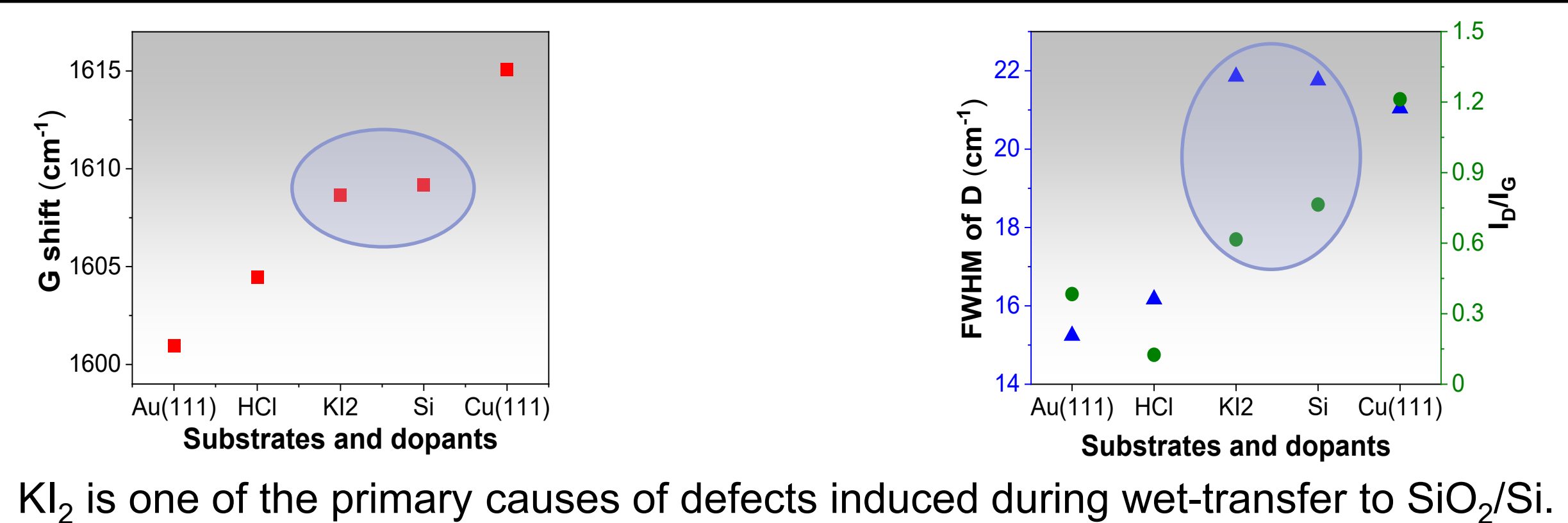
Growth on metallic substrates



Doping with HCl and KI₂

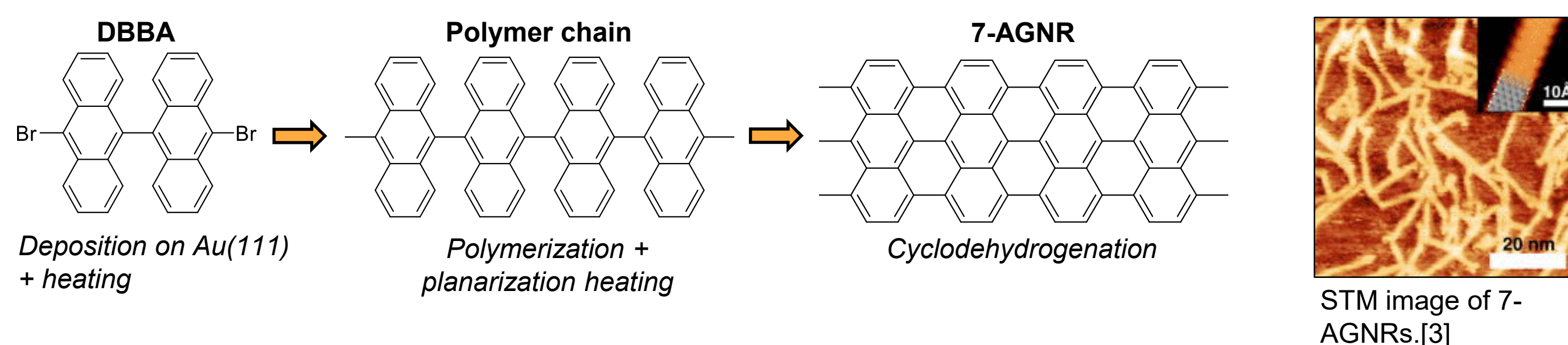


Transfer to insulating substrates

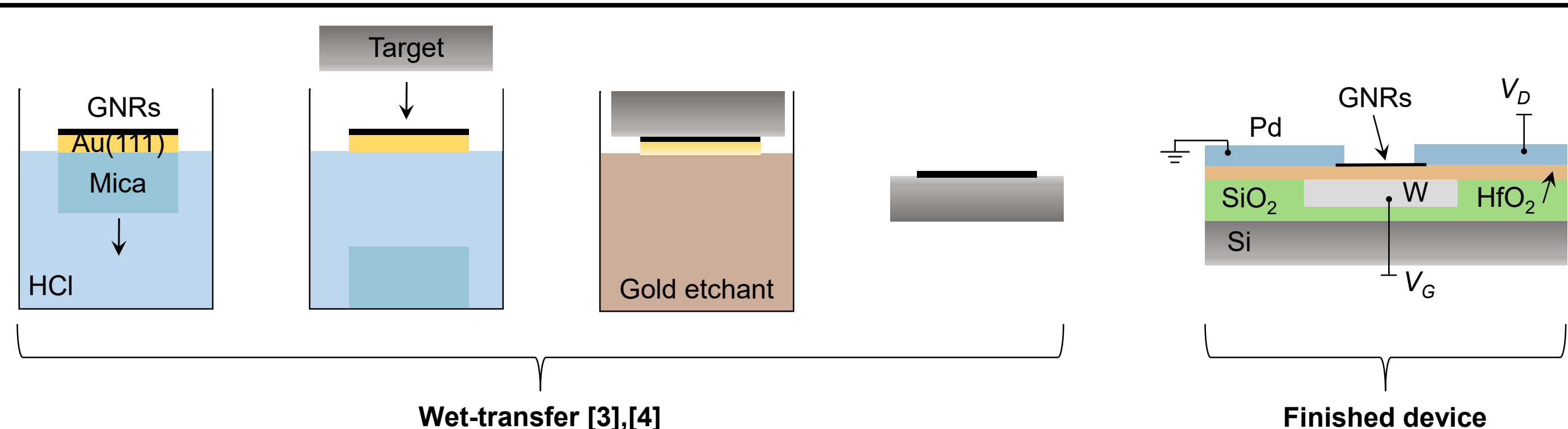


Methods

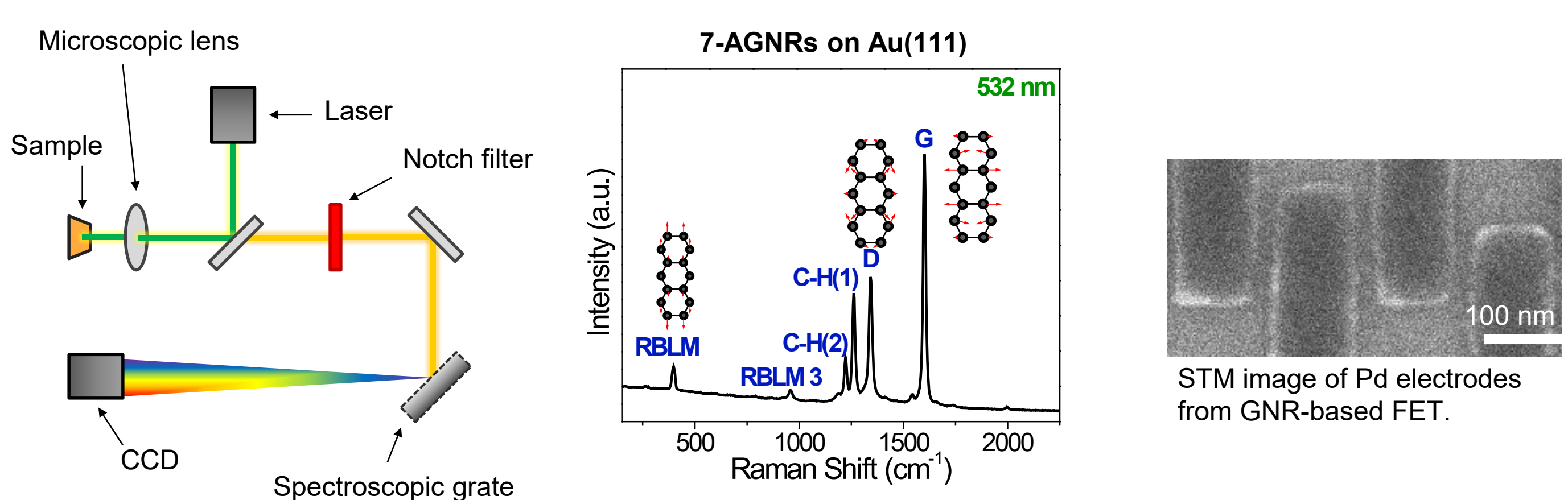
Bottom-up synthesis [1]



Transfer method and device fabrication



Raman spectroscopy and STM characterization



Conclusion

- Raman spectroscopy has applications beyond GNR type identification.
- Alternative transfer methods or etchants should be explored to reduce defects induced during transport to insulating substrates.
- With further research, we hope to confirm the trends noted in this work so that the G and D Raman modes may be used to probe changes in GNR band structure caused by doping and lattice strain.

References

- [1] Cai, J. et al., "Atomically precise bottom-up fabrication of graphene nanoribbons." Nature (2010).
- [2] Yang, L. et al., "Quasiparticle Energies and Band Gaps in Graphene Nanoribbons." Phys. Rev. Lett. (2007).
- [3] Bennett, P. et al., "Bottom-up graphene nanoribbon field-effect transistors." Appl. Phys. Lett. (2013).
- [4] Llinas, J. et al., "Short-channel field-effect transistors with 9-atom and 13-atom wide graphene nanoribbons." Nature Communications (2017).
- [5] B. V. Senkovskiy et al., "Making Graphene Nanoribbons Photoluminescent." Nano Lett. (2017).
- [6] H. Huang et al., "Spatially Resolved Electronic Structures of Atomically Precise Armchair Graphene Nanoribbons." Scientific Reports, (2012).

Acknowledgements

I would like to thank the following people: Nicole McIntyre and Sam Mountain for their exceptional administrative support, Dr. Zafer Mutlu for his invaluable mentorship and guidance, and Professor Jeffrey Bokor for allowing me to conduct this research as a remote member of the Bokor lab group. I would also like to acknowledge the Center for Energy Efficient Electronics Science as well as the National Science Foundation for funding this project. Raman spectroscopy was performed at the Molecular Foundry at Lawrence Berkeley National Laboratory (LBNL), supported by the Office of Science, Office of Basic Energy Sciences, of the U.S. Department of Energy (DOE) under contract No. DE-AC02-05CH11231. Device fabrication was performed at the Stanford Nano Shared Facilities (SNSF) at Stanford University.

Contact Information

Wyatt Jebef
Email: wyattjebef@gmail.com

Support Information

This work was funded by National Science Foundation Award ECCS-0939514 & ECCS-1461157

