Atomically Precise Graphene Nanoribbons (GNRs)

Anthony Brandon Jr.[1], Juan Pablo Llinás[2], Byung Yong Choi, Ph.D.[2], Jeffrey Bokor, Ph.D.[2]

[1]Howard University, [2]University of California, Berkeley

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Abstract

According to Moore's law, the density of transistors in a computer chip should double every two years. With current silicon-based transistors, the probability of keeping this law factual is on a downward slope unless an alternative is found. Atomically precise graphene nanoribbons (GNRs) have the potential to become the replacement for silicon transistors due to their predicted superior electrical qualities and ultrathin body. We fabricated GNR field effect transistors (FETs) using atomically precise GNRs with 20 nm channel lengths and an I_{on}/I_{off} ratio in which the I_{on} was 1000 times higher than the I_{off} current. The GNRs are environmentally sensitive when characterized due to adsorbed oxygen at the contact.

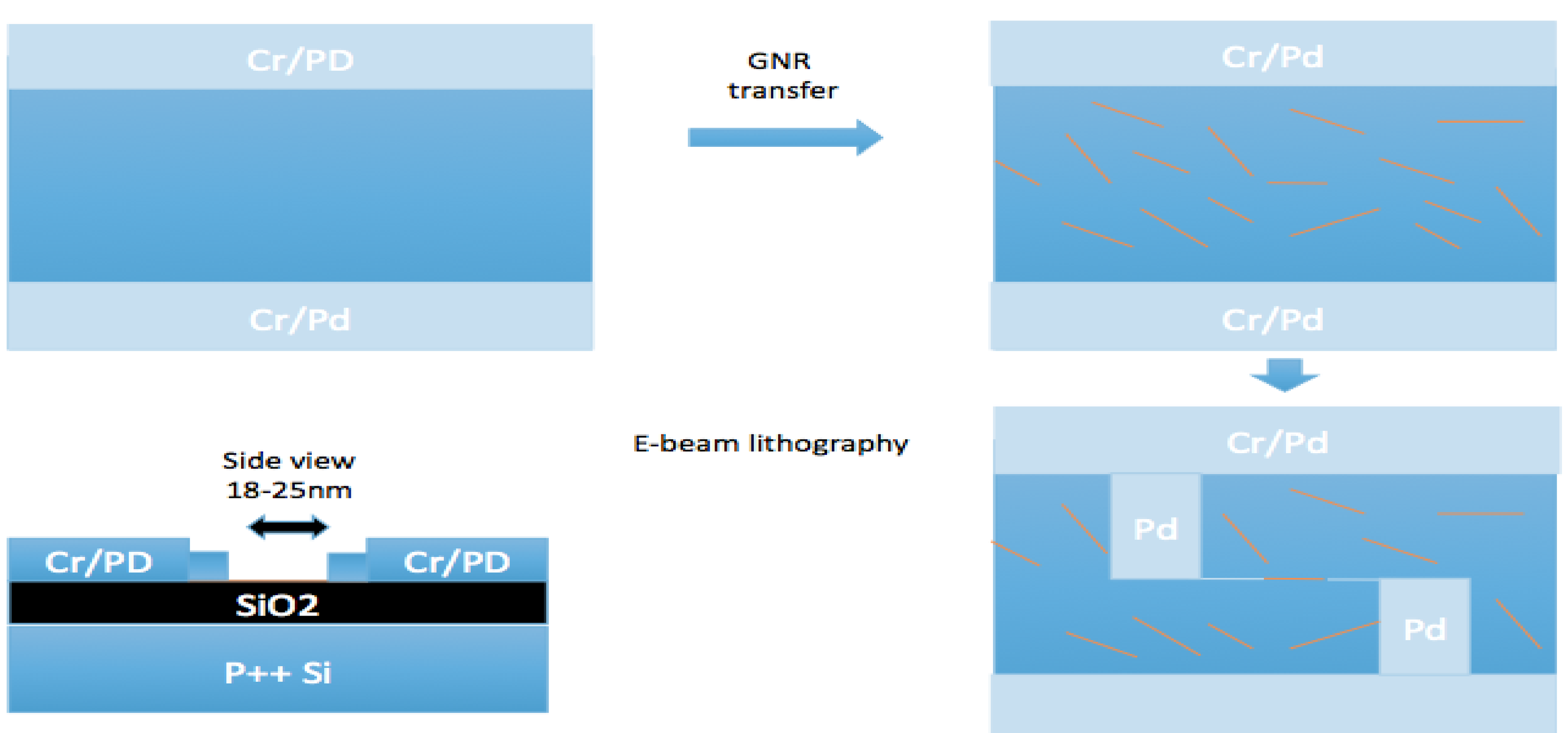
Research Objectives

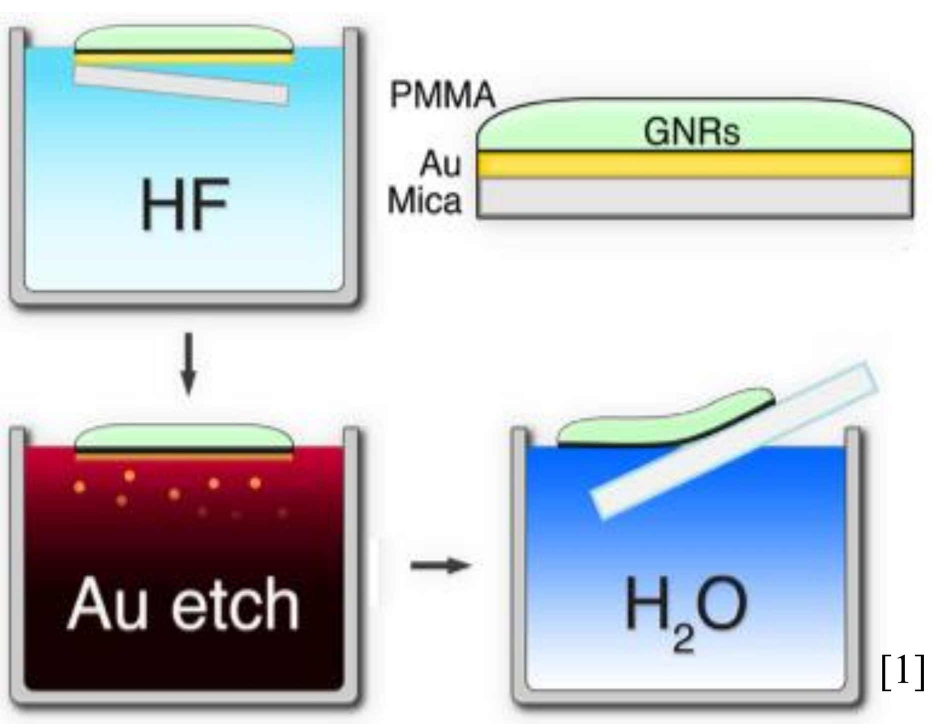
Integrate GNRs into electronic devices

- Find an alternative to silicon Field Effect Transistor (FET) using GNRs
- Improve performance and yield of GNR devices
- Alternative to carbon nanotubes (CNT) as high-performing semiconducting channel material
- Measure and characterize their electronic responses through transport and optical spectroscopy

Fabrication

The bottom-up process to prepare atomically precise GNRFETs consists of GNR synthesis on metals and subsequent transfer to insulating substrates. Using E-beam lithography and liftoff, Pd pads are are placed onto the substrate with gaps ranging from 15-25 nm to conduct transport measurements. These GNRs are exactly 7 carbon atoms across with a band gap of 2.5 eV and a width of 0.74 nm.





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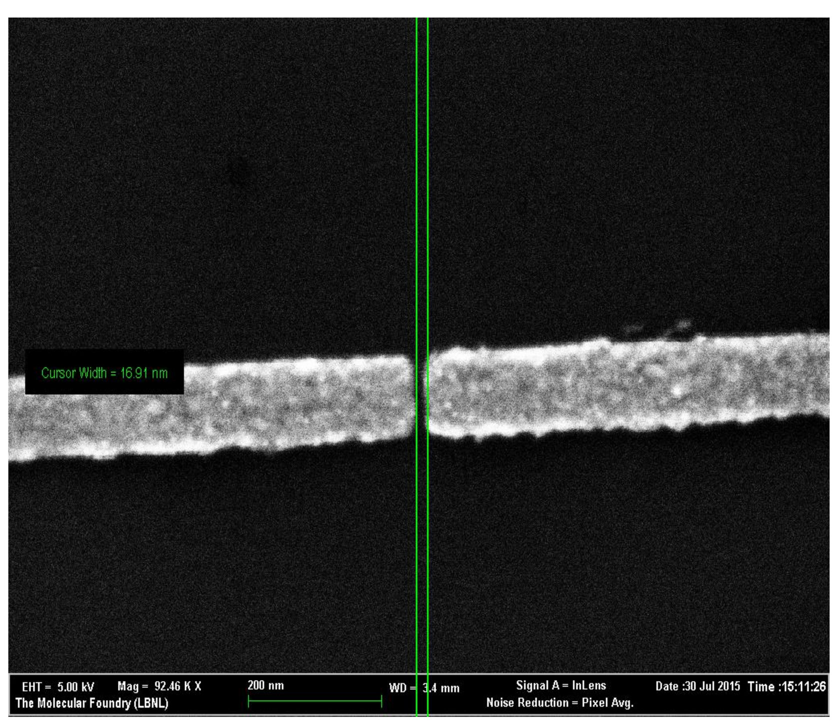
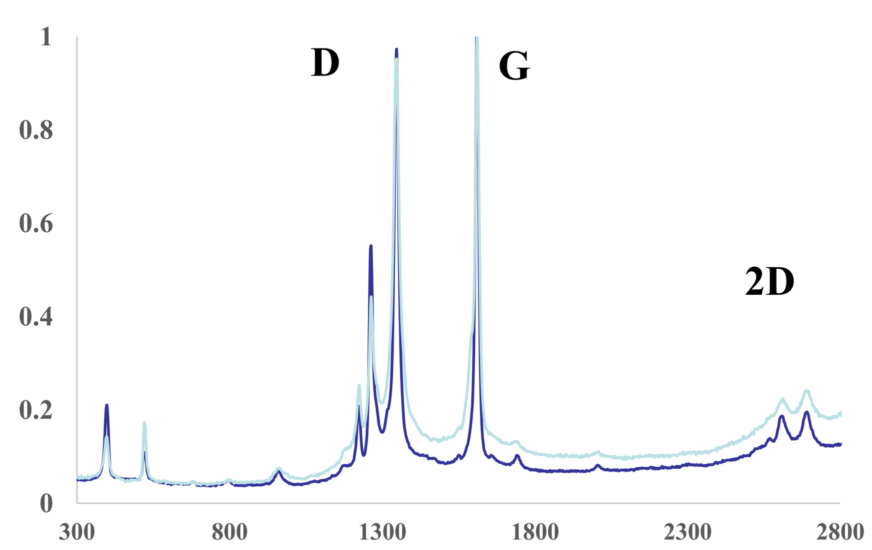


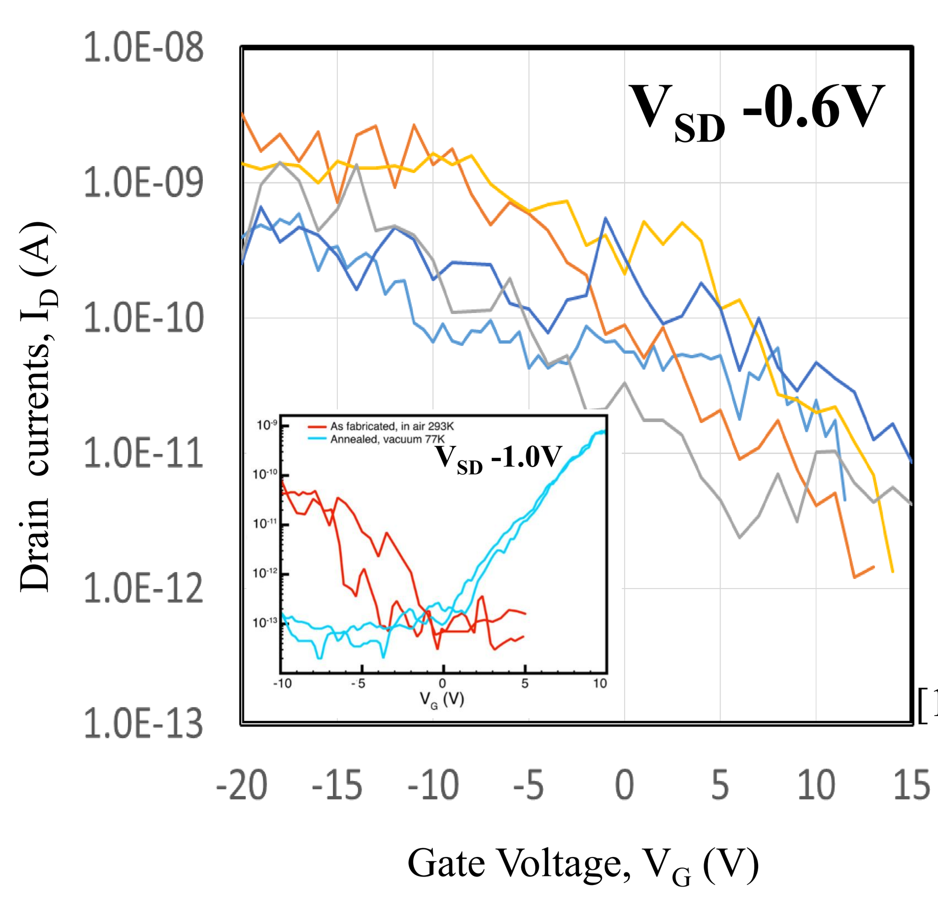
We used three different transfer methods which include the HF transfer, HCL transfer, and powder transfer. It is extremely critical to have an effective transfer because the more GNRs transferred, the more chances we have to measure working devices.

Above is a SEM image of source/drain after e-beam and lift-off process. The GNRs can be as long as 25-40 nm. Therefore, it is crucial to contact ribbons at both the source and the drain with a very narrow and precise gap.

Results



Raman spectra of fabricated GNRs after transfer onto oxide substrate and device fabrication. Ideal graphene has two main peaks in its Raman spectrum, which are the G and 2D peak. The D peak is a disorder peak.



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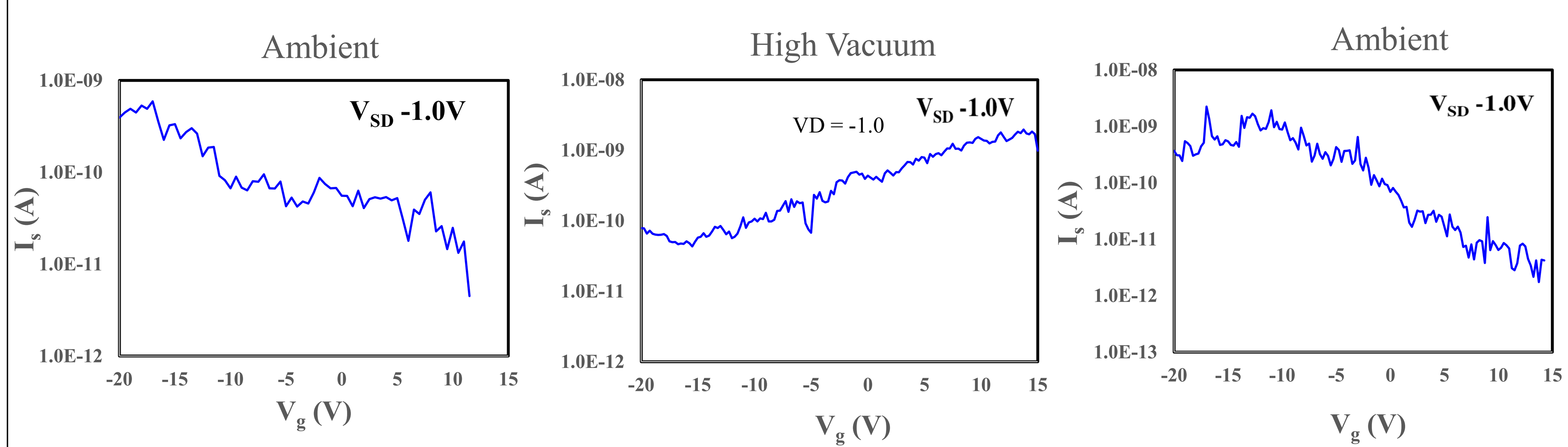
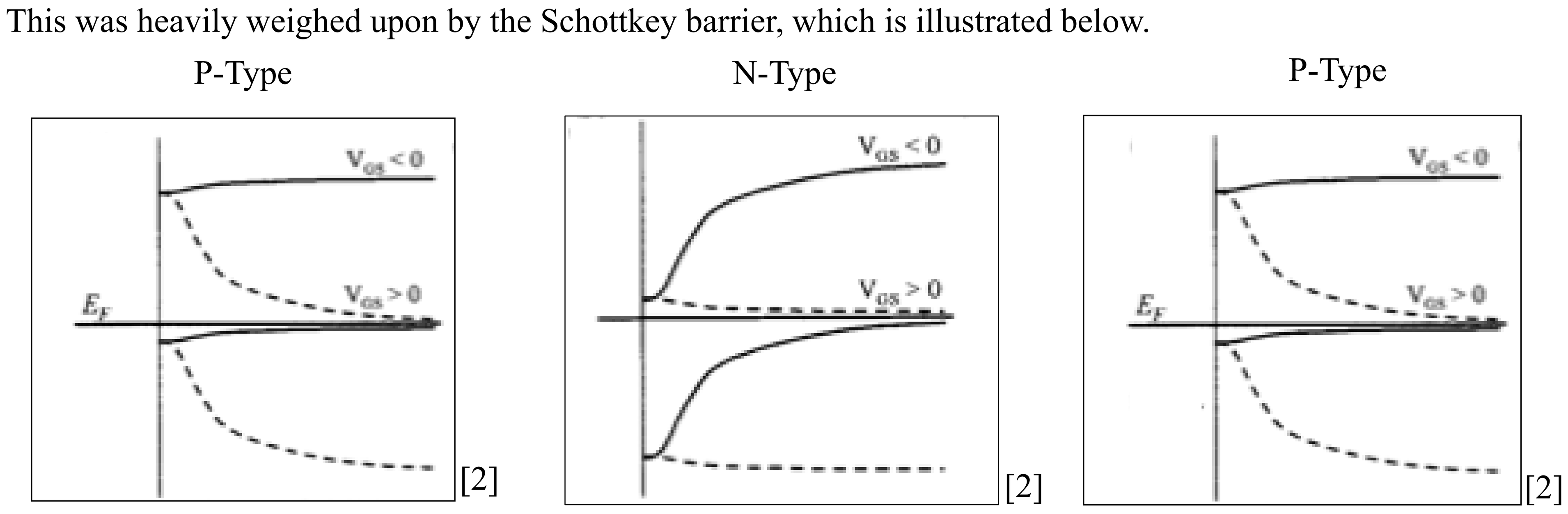
This graph represents the electrical characteristics of multiple GNR transistors measured in air. The smaller figure is the previous work obtained by our predecessors. The low-yield of our devices is a result of the random position and orientation of the ribbons. GNRs contacted with Pd source/drain metals in air have P-type conduction. Compared to the average Si transistors, these I_{on} are low. This has to do mainly with the height of the Schottky barrier, which is affected by the metal itself, water, interaction at the interface, contamination, absorbed oxygen, and the measurement environment. The I_{off} represents how much energy is being wasted in the off state.



Device behavior switches from P-type when measured in air to N-type when measured under cryogenic conditions in the probe station. The device then switches back to P-type when measured in ambient conditions. This was heavily weighed upon by the Schottky barrier, which is illustrated below.



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Future Work

- Try GNRs with the following characteristics: N=9, 0.9 nm width, and 1.9 eV band gap; N=13, 1.3 nm width, and 2.5 eV band gap
- Make shorter gaps precise enough to not short on every measurement
- Try different contact metals other than Pd
- Increase yield to about 20 devices per chip

Support Information

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References

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Contact Information

(919) 247-5348

anthony.brandon@bison.howard.edu

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