Local Measurement of Graphene Electronics using Gate Mapping Tunneling Spectroscopy

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CNST Center for Nanoscale Science & Technology

NIST National Institute of Standards and Technology U.S. Department of Commerce

Project Overview

Goal

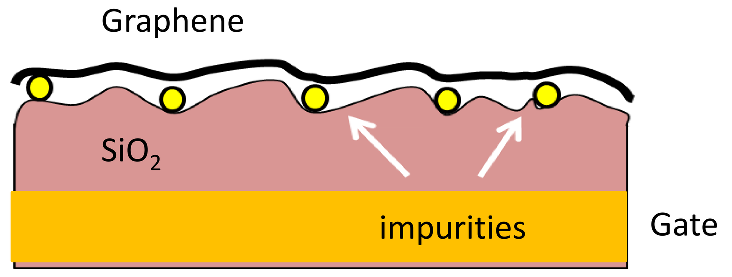
- **Develop new microscopic measurement methods to investigate future electronic materials in real device geometries**

Application – Future Electronic Materials/Nanofabrication

- **Determining the role of the reduced disorder potential by using h-BN spacers**
- **Determining how electron interactions change carrier velocities**

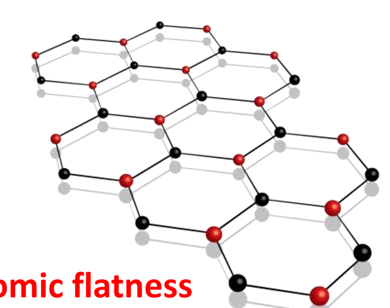
Graphene on h-BN

Substrate induced scattering



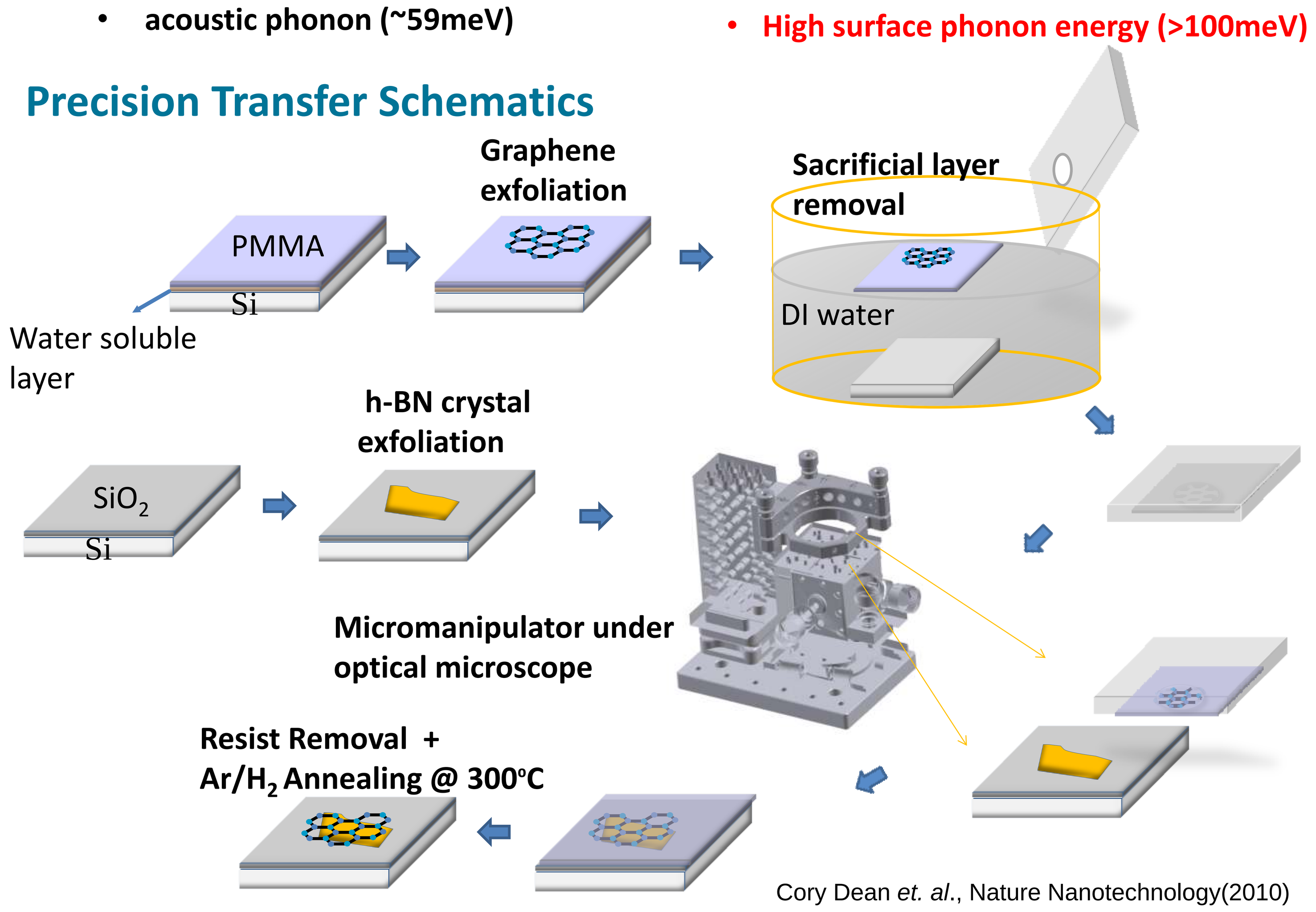
- ripples
- charge traps
- acoustic phonon (~59meV)

Hexagonal – Boron Nitride



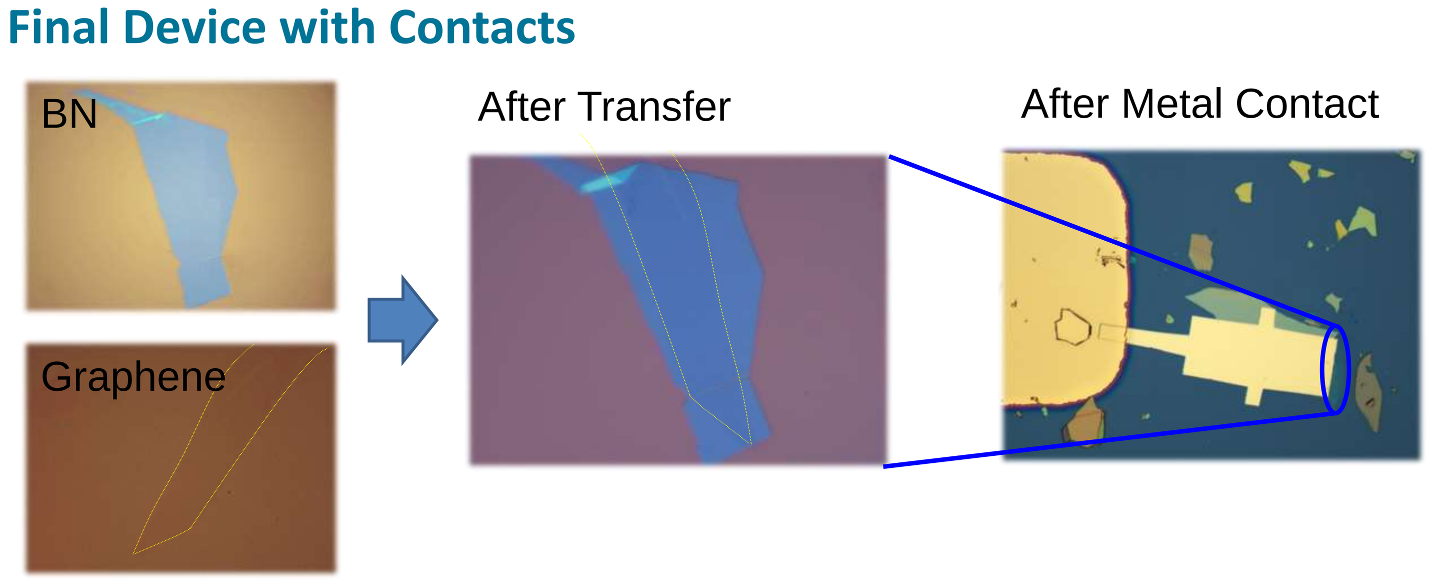
- Atomic flatness
- Low charge traps
- High surface phonon energy (>100meV)

Precision Transfer Schematics

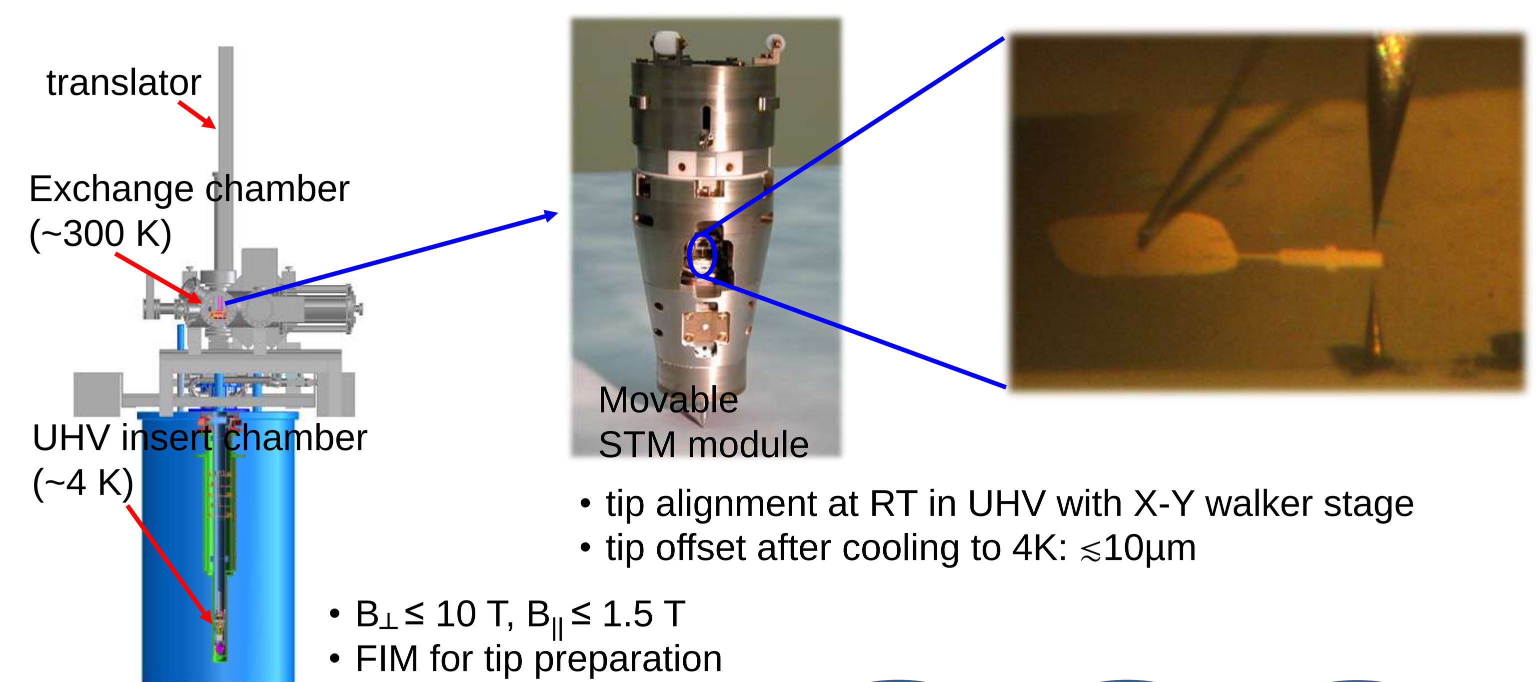


Cory Dean *et. al.*, Nature Nanotechnology(2010)

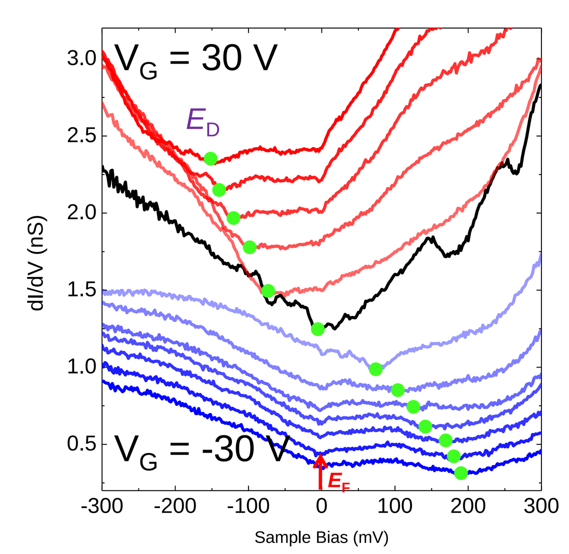
Final Device with Contacts

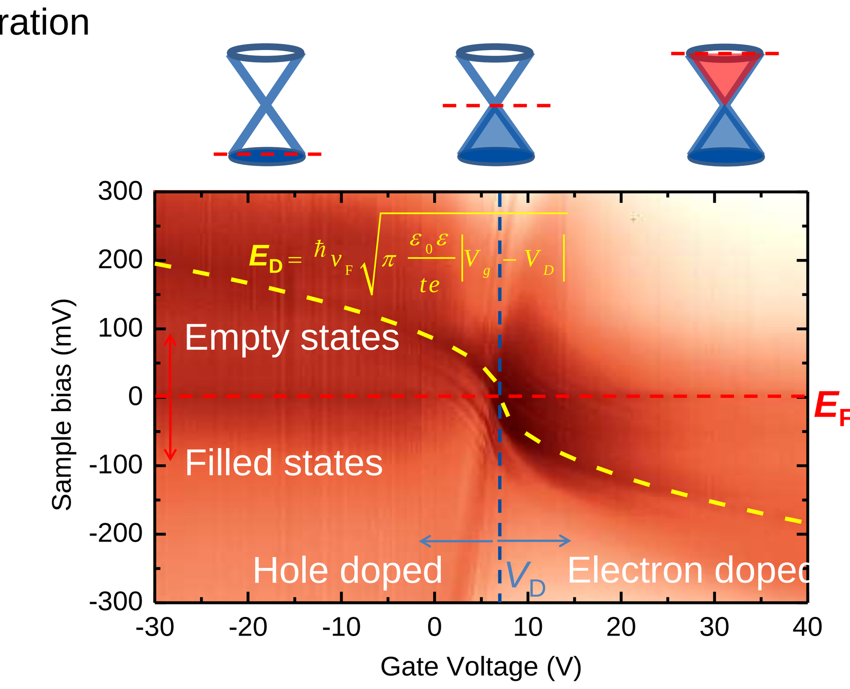


Tip Alignment/Gate Map Spectroscopy



- tip alignment at RT in UHV with X-Y walker stage
- tip offset after cooling to 4K: ≲10µm
- $B_\perp \leq 10$ T, $B_{||} \leq 1.5$ T
- FIM for tip preparation

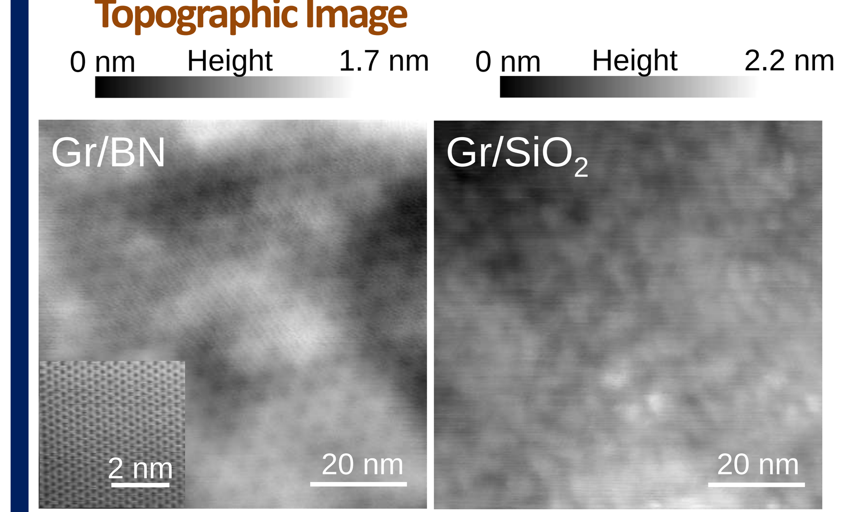




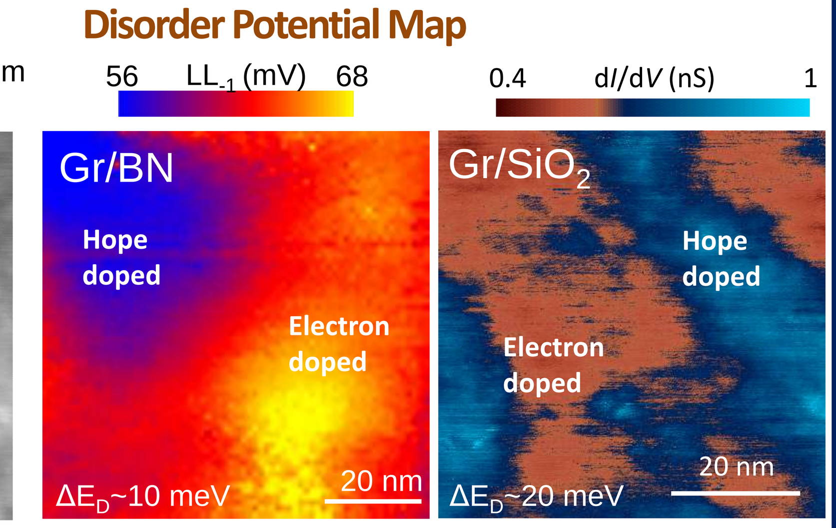
Reduced Disorder by h-BN Spacer

Comparison of Graphene on SiO_2 and BN Substrates

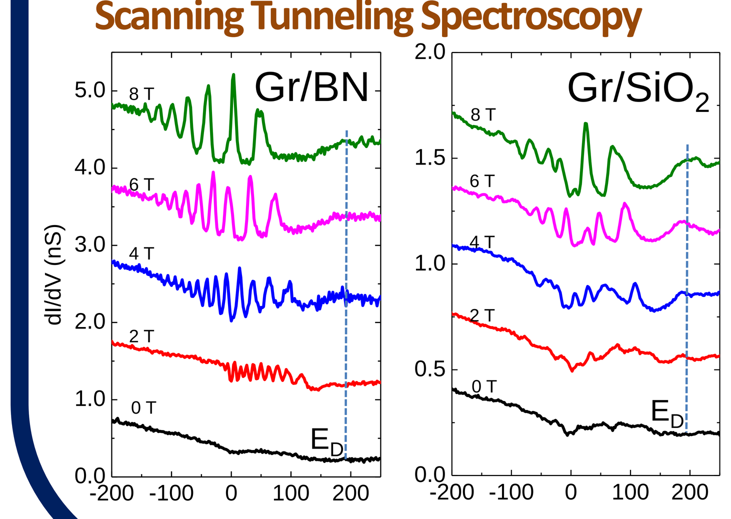
Topographic Image



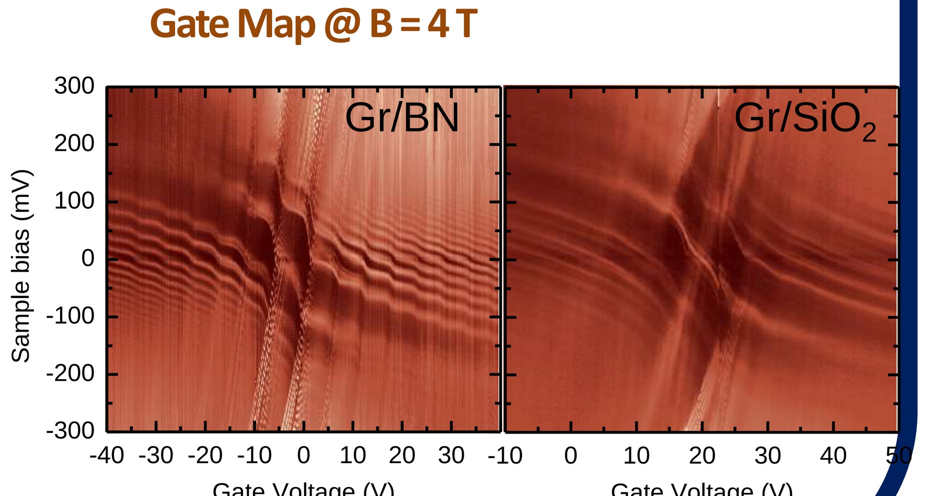
Disorder Potential Map



Scanning Tunneling Spectroscopy

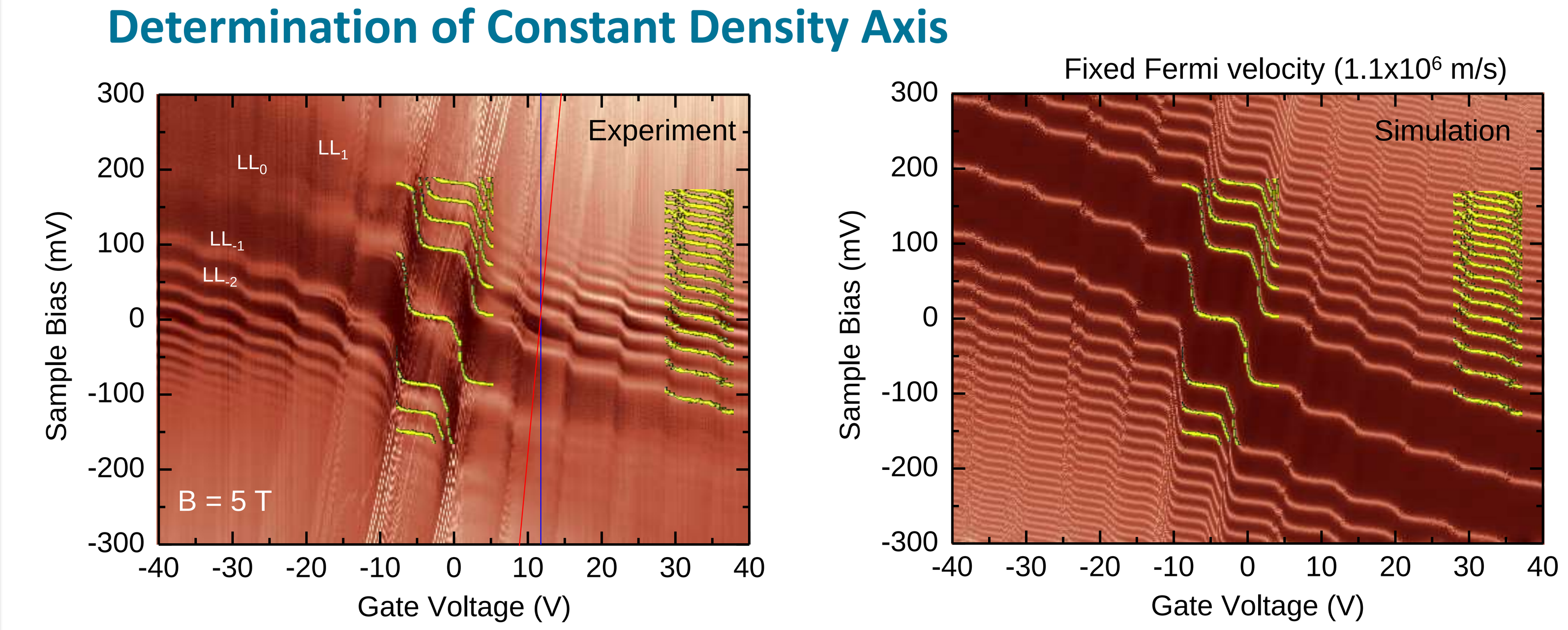


Gate Map @ B = 4 T



Fermi Velocity Renormalization

Determination of Constant Density Axis



- **Simulation of gate map shows that local gating by the STM tip voltage results in a tilted angle of Landau level pinning positions, effecting the true energy and density positions.**
- **Deviation from single particle physics is observed at low carrier density regime.**

Electron-electron Driven Fermi Velocity Renormalization

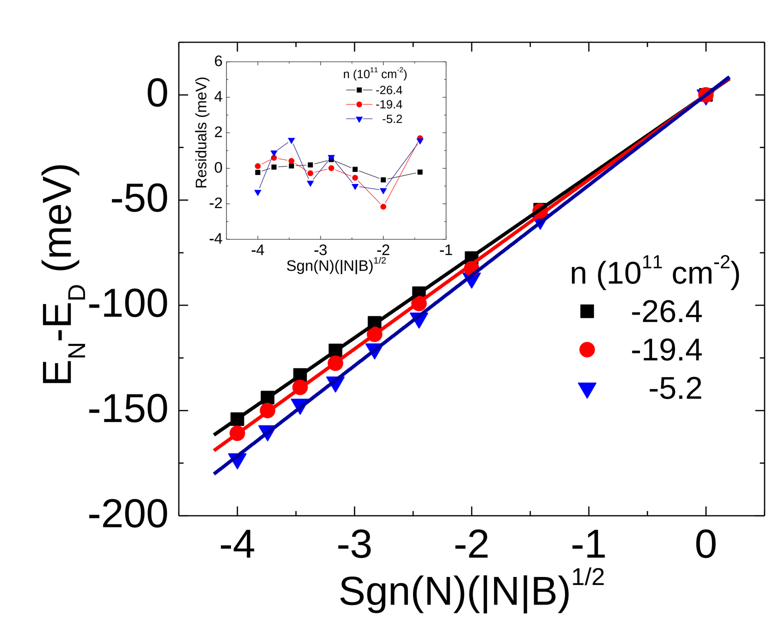
Landau Level Quantization in Graphene

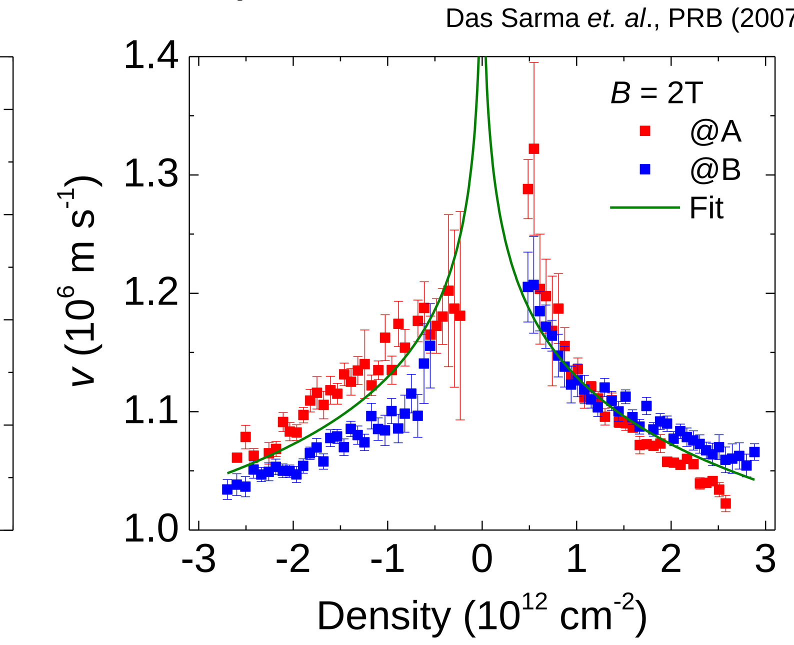
$$E_N = \mathrm{sgn}(N)\sqrt{2e\hbar v_F^2|N|B}$$

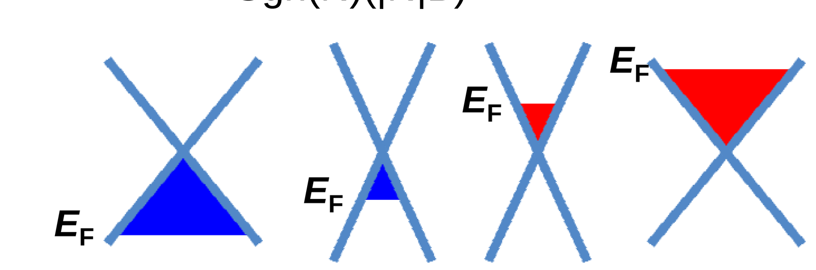
Renormalized Fermi Velocity

$$\frac{v_F(n)}{v_F} = 1 - \frac{r_s}{\pi}\left[\frac{5}{3} + \ln(r_s)\right] + \frac{r_s}{8}\ln\left(\frac{n_c}{n}\right)$$

Das Sarma *et. al.*, PRB (2007)







Fitting parameters

v_F = (0.957±0.003) x 10^6 m/s

r_s = 0.69±0.03

- Linear dispersion is preserved within an energy range of ±200 meV
- Fermi velocity is increased as density approaches the Dirac point

Jungseok Chae *et al.* Renormalization of the Graphene Dispersion Velocity Determined from Scanning Tunneling Spectroscopy. **PRL** (2012)

Conclusions

- **Graphene devices on BN substrates were fabricated using precision transfer techniques.**
- **STM/STS measurements of graphene on BN substrates shows an improvement compared to that of graphene on SiO_2 substrate.**
- **A change in the carrier velocity due to electron interactions was determined as a function of carrier density with a preservation of the light-like linear dispersion.**