Conductance Fluctuations in Fabricated h-BN/graphene/h-BN Devices at Low Temperatures

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Improved understanding of graphene device characteristics is needed for the development of nanoelectronics.[1] Inherent scattering and impurities in graphene/SiO_2 devices causes the majority of characterization to be carried out in the diffusive transport regime. Better-quality characterization can now take place because there has been advancement in fabricated graphene/hexagonal boron nitride (h-BN) devices. Hexagonal boron nitride has an atomically smooth surface with no dangling bonds and a small lattice mismatch with graphene, making it a promising substrate for graphene-based nanoelectronics.[1] Quasi-ballistic and ballistic transport regimes can now be explored, and this project focuses specifically on the conductance fluctuations that take place in fabricated h-BN/graphene/h-BN devices in the quasi-ballistic regime. Conductance fluctuations can be used to evaluate device quality because they have distinct characteristics that can be used to infer information about the transport properties of their respective samples.[2] While prior work has investigated the nature of the conductance fluctuations in disordered graphene, exfoliated on SiO_2 substrates,[3] there have been no systematic reports of this phenomenon in higher-quality graphene isolated on BN. We have fabricated such devices and have studied their conductance fluctuations by applying a magnetic field perpendicular to the device. Conductance fluctuations generated by varying both magnetic field and gate voltage are investigated at low temperatures ($\geq$0.3 K). In our presentation we discuss the differences exhibited by the quantum fluctuations in these samples, and those exhibited[3] by lower-quality graphene. Our efforts contribute to the need for increased knowledge about graphene's unique transport properties and the invention of new nanodevices.

[1] C.R. Dean, *et. al.,* Nature Nanotech. **5,** 722 (2010).

[2] D. F. Holcomb*,* Am. J. Phys. **67**, 278 (1999).

[3] G. Bohra, *et al.,* Applied Physics Letters **101**, 093110 (2012).

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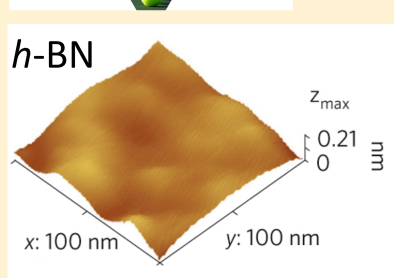
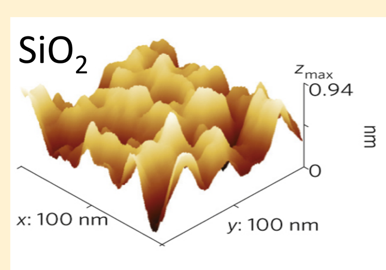
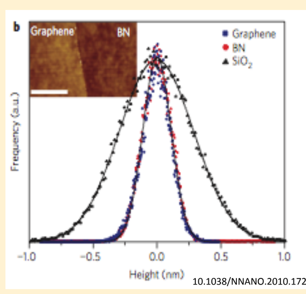
Background

- Graphene has extremely useful properties such has high conductance
- Preservation of graphene's properties is increasingly important in nanotechnology to improve applications (see left for examples)



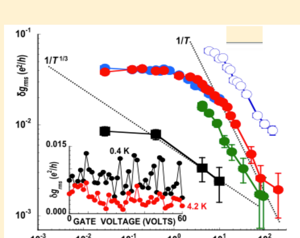
STM topographic images of graphene-on-SiO2 & graphene-on-*h*-BN





Surface height distribution of graphene-on-SiO$_2$ and graphene-on- *h*-BN measured using AFM

- Graphene devices have been traditionally fabricated using SiO$_2$
- Higher quality devices can now be fabricated using *h*-BN - a substrate with an atomically smooth surface

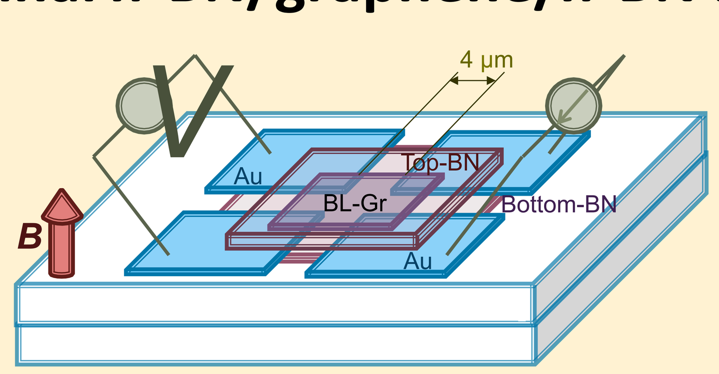


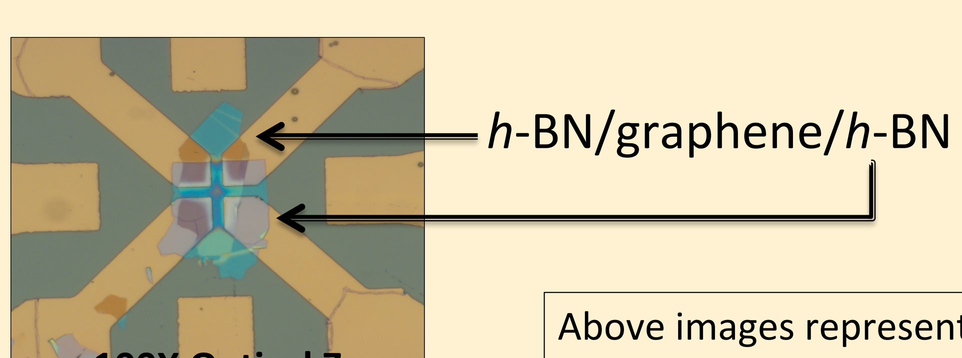
- Research has studied a phenomenon called conductance fluctuations (CF) in disordered graphene on SiO$_2$
- CF can now be studied in higher quality graphene devices at low temperatures (≥0.3K)
- A noticeable trend in this project will be the Quantum Hall Effect (QHE)
- Quantum Hall Effect – Two dimensional phenomena in which the Hall resistance, R_{xy}, measured with varying magnetic field or carrier density values, is found to have quantized levels in the form of oscillations or plateaus
- Studying CF improves knowledge of properties of graphene nanodevices and can be used for device quality comparisons

Experimental Method

- Sample cooled in ^{3}He Cryostat
- Magnetic field and gate voltage are varied
- Sample conductance and resistance are probed
- Data collected and analyzed

4-Terminal *h*-BN/graphene/*h*-BN Device





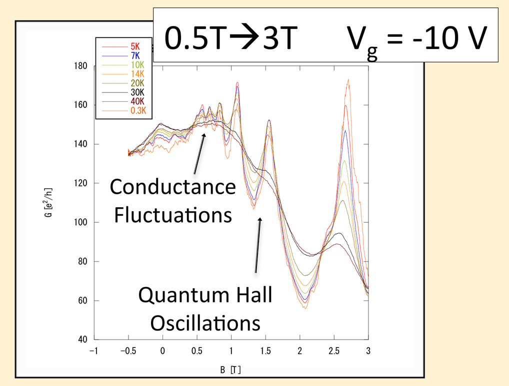
Above images represent a schematic and optical image of tested device

Goal

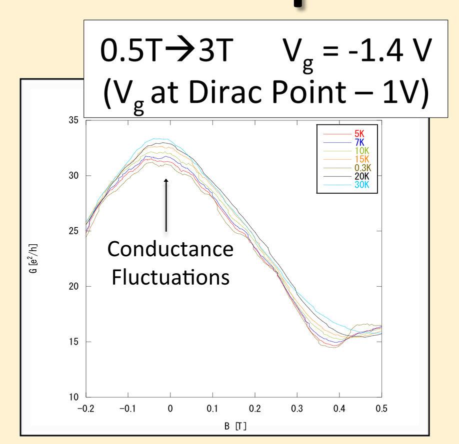
Investigate conductance fluctuations generated by varying both magnetic field and gate voltage at low temperatures in improved graphene devices

Magnetic Field Sweep

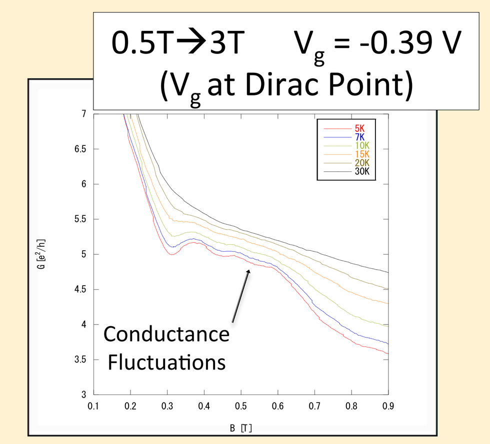
Overall Observation: Conductance fluctuations become less pronounced as sample temperature is increased and are barely detectable at and above 20 K



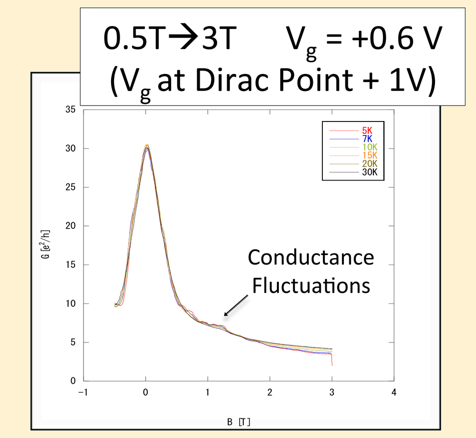
Low Mobility Region



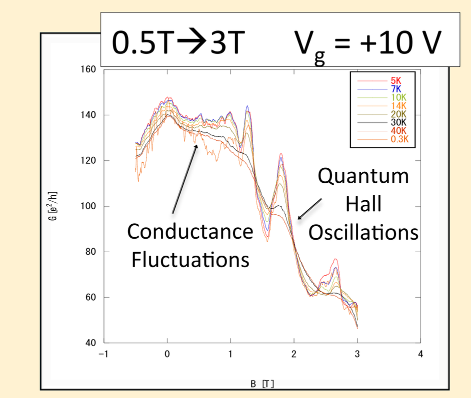
High Mobility Region



Low Mobility Region

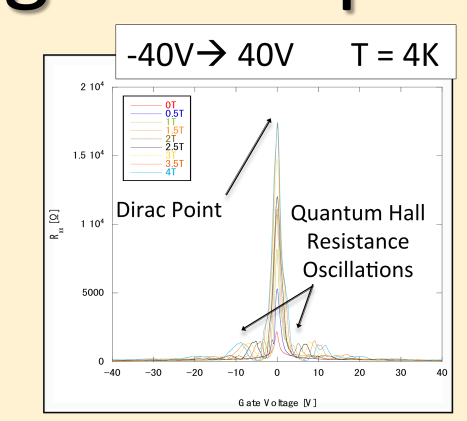


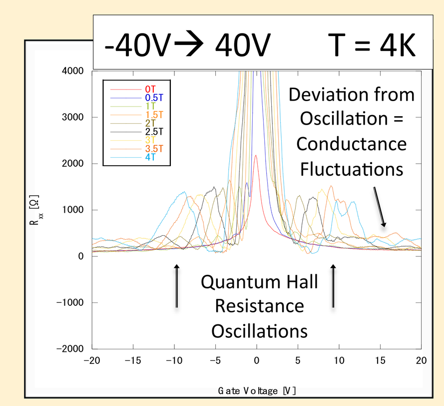
High Mobility Region

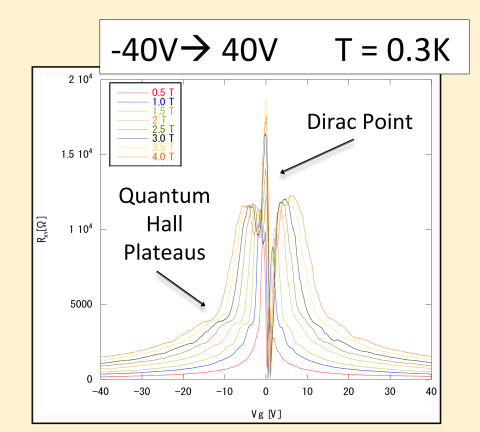


Low Mobility Region

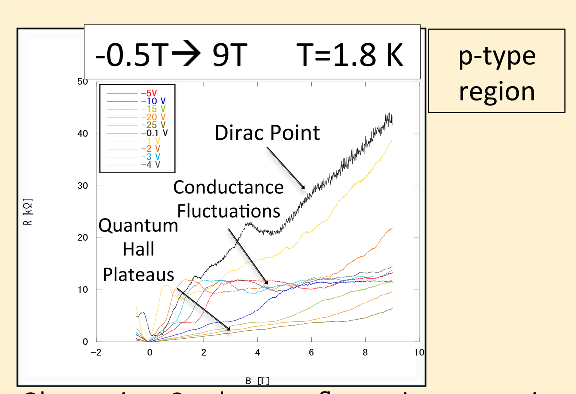
Gate Voltage Sweep

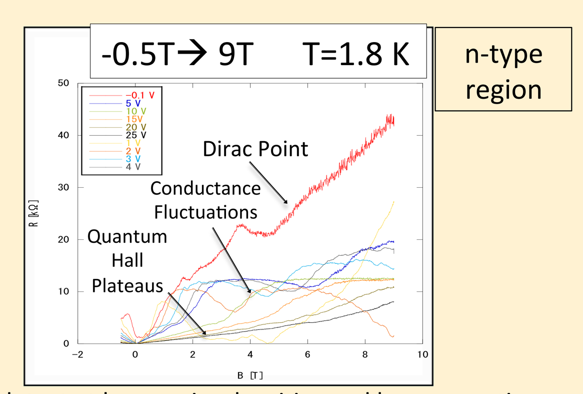




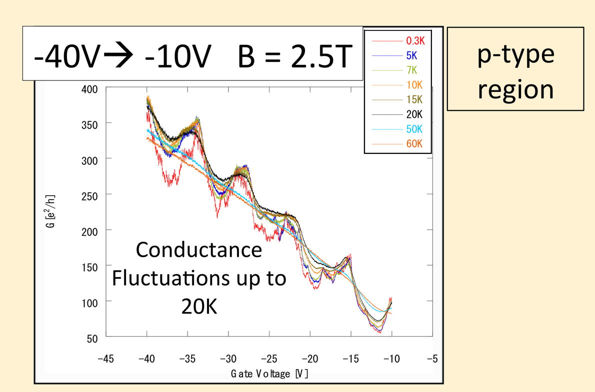


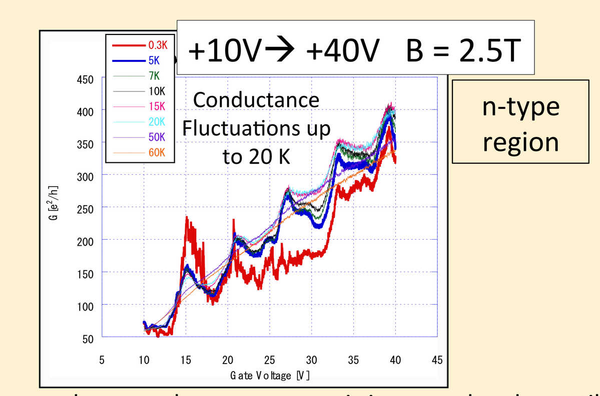
Observation: Plateaus due to Quantum Hall Effect are not detected in low B-field strengths making conductance fluctuations easier to detect in those regions





Observation: Conductance fluctuations are easier to detect at low carrier densities and low magnetic field strengths



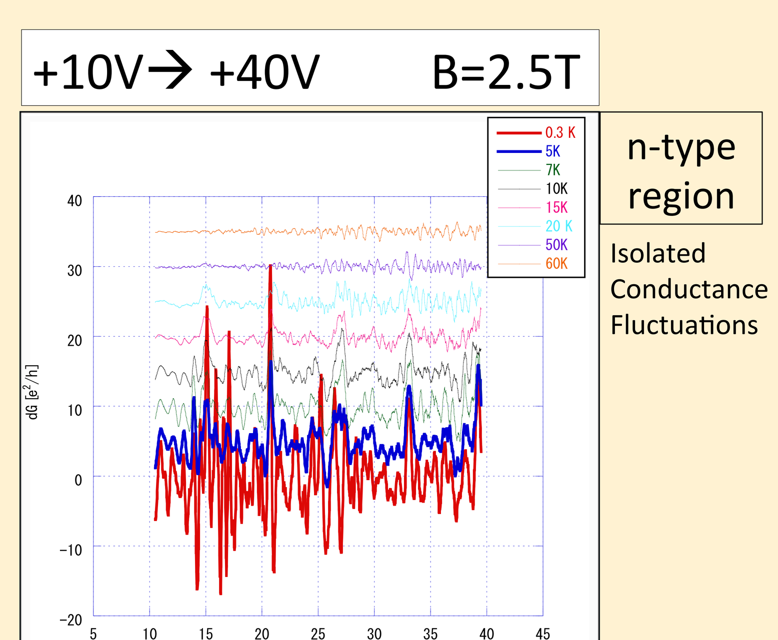


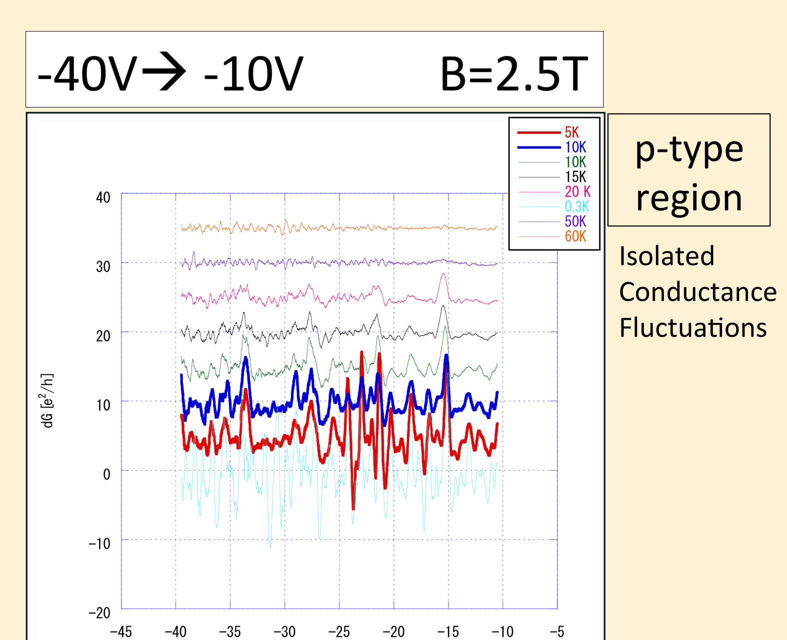
Observation: Conductance fluctuations stay more pronounced as sample temperature is increased and are still detectable at 20 K

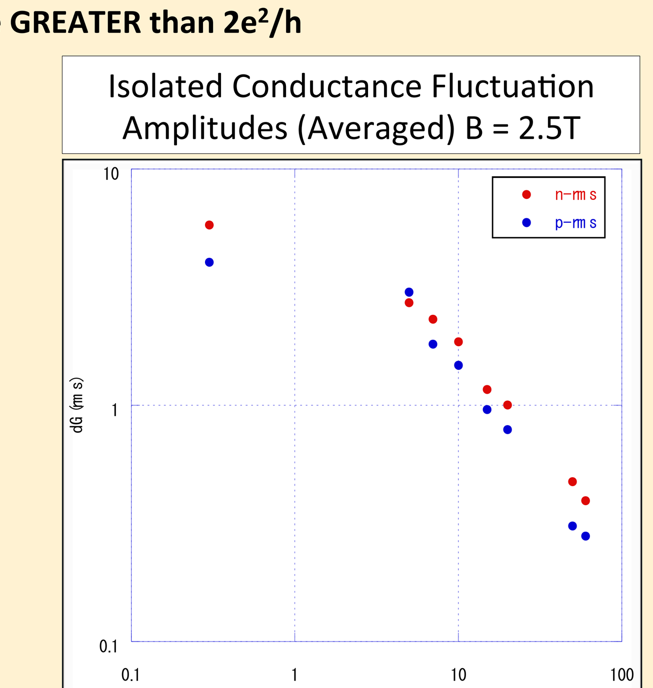
Temperature Dependence

Overall Observations:

- **Large fluctuations are directly found in experimental data – before the subtraction of background**
- **Low temperature fluctuation amplitudes are GREATER than 2e^2/h**







Observation: Conduction fluctuation amplitude is inversely affected by temperature

Conclusions

- Graphs showing such **robust** CF are a great result
- CF are **a real effect** in graphene nanodevices
- Carrier density dependent CF are less affected by temperature than magnetic field dependent CF
- CF are stronger at low temperatures (0.3-40K) and low mobility regions

Significance

- Variable dependent CF amplitudes means graphene exhibits different properties than other semiconductors which have been found to be ergodic
- Conductance fluctuations do exist in preserved graphene devices

Future Work

- Confirm CF in other samples through more testing
- Improve graphene devices by altering fabrication methods and studying effect on CF

References

- C.R. Dean, *et. al.*, Nature Nanotech. **5,** 722 (2010).
- D. F. Holcomb, Am. J. Phys. **67**, 278 (1999).
- G. Bohra, *et al.*, Applied Physics Letters **101**, 093110 (2012).

Acknowledgements

This research project was conducted as part of the 2014 NanoJapan: Internalonal Research Experience for Undergraduates program with support from a Nalonal Science Foundalon Partnerships for Internalonal Research and Educalon grant. For more informalon on NanoJapan, see hOp://nanojapan.rice.edu.

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