Molecular Detection in Liquid by Hall Effect Measurements of Graphene

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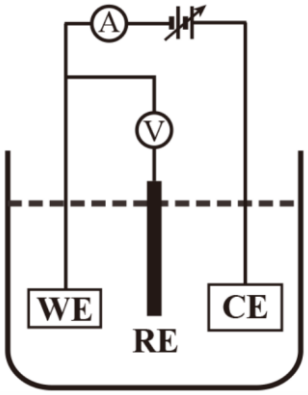
Outline

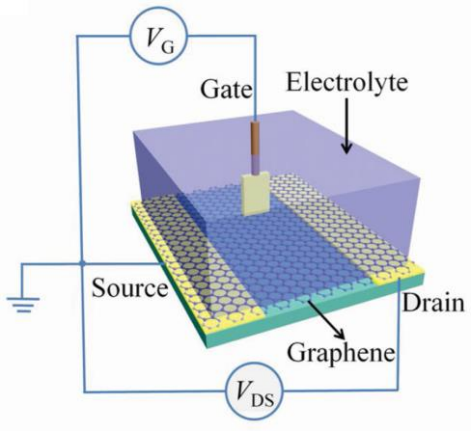
- Introduction to electronic bio-sensors
  - Categories and principles
- Fabrication of graphene Hall structures
  - Avoid the number of contacts of graphene with chemicals
- Detection of L-histidine in the pM range
  - Demonstration of bio-sensing in low concentration
- Detection of urea in the mM range
  - Demonstration of bio-sensing in high concentration
- Discussion of the sensing mechanism
  - Magnetotransport, quantum capacitance, EDL capacitance, ‘band diagrams’, and so on
- Conclusion

Introduction to electronic bio-sensors - 1

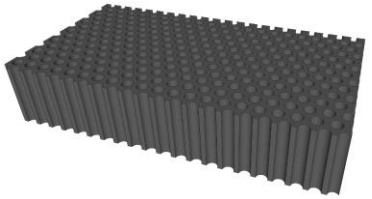
- Categories of electronic bio-sensors



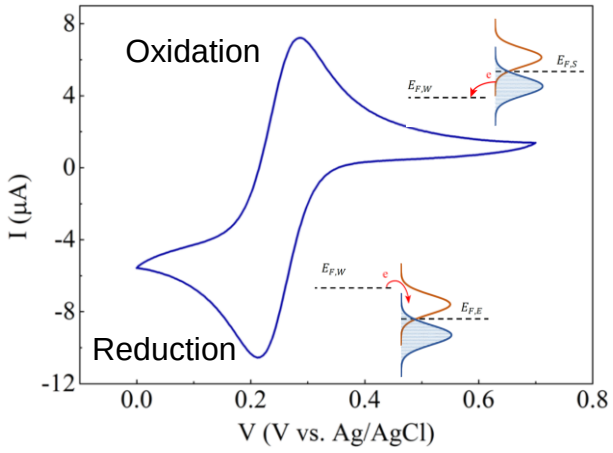
Amperometric

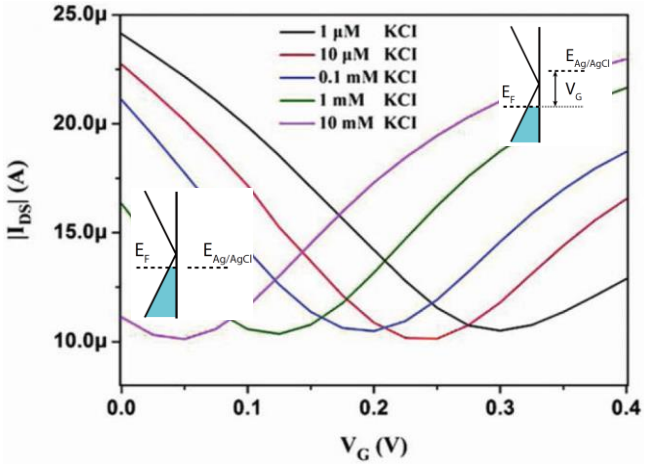


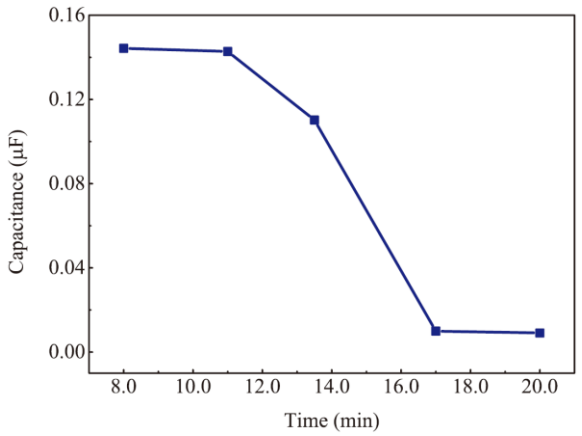
Potentiometric*



Capacitive**





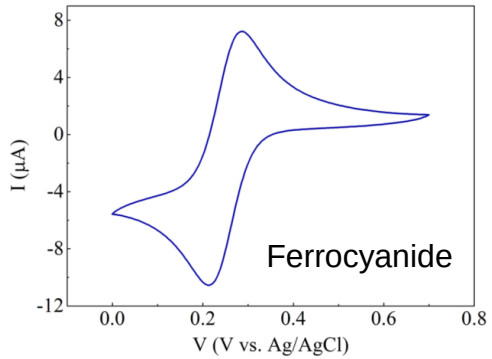


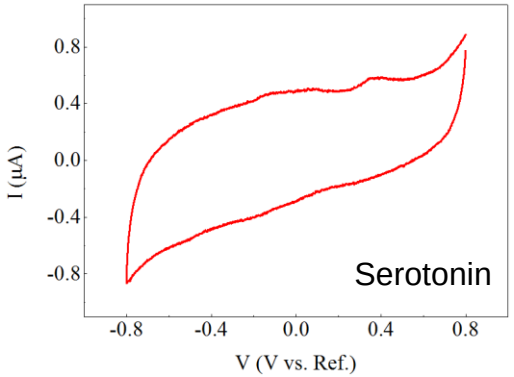
* Feng Yan, et. al. *Adv Healthc Mater*, 3(3):313-331, 2014

** Hualin Zhan , et. al. *Scientific Reports*, 6:19822, 2016

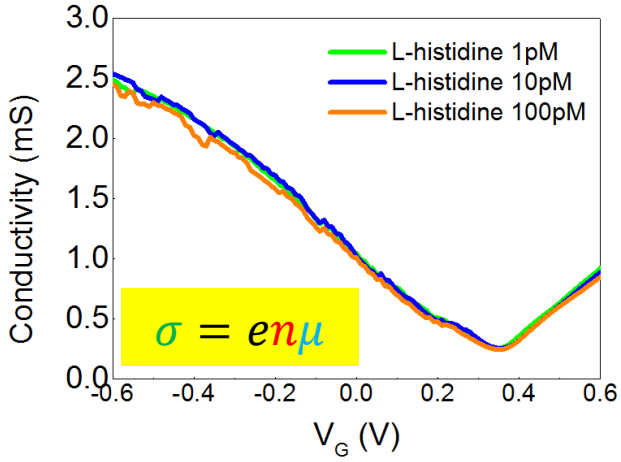
Introduction to electronic bio-sensors - 2

- Issues
  - Amperometric: only able to detect molecules which are electrochemically active.

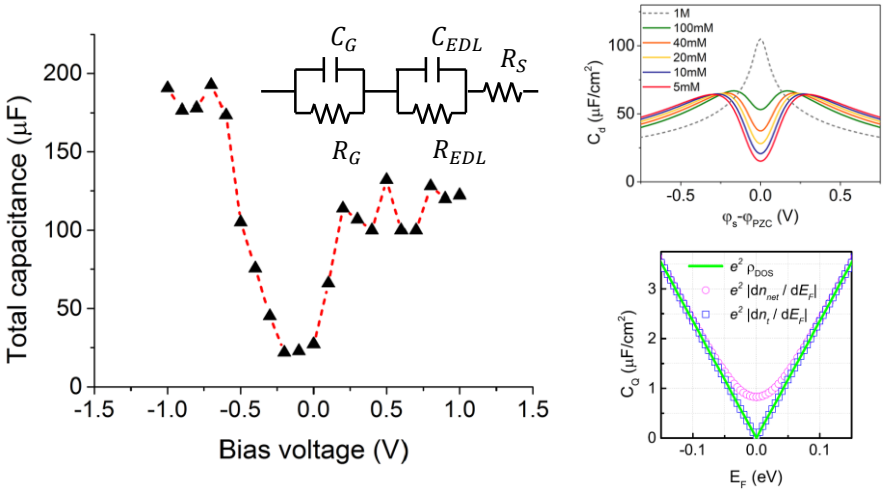




- Potentiometric:
  Insensitive in some cases.



- Capacitive*:
  EDL capacitance**? Quantum capacitance?

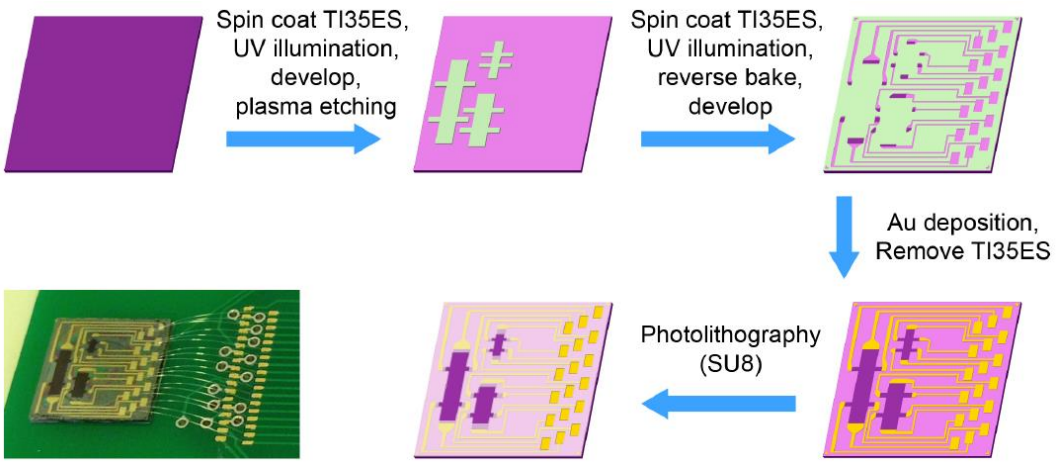


* Hualin Zhan , et. al. *Scientific Reports*, 6:19822, 2016

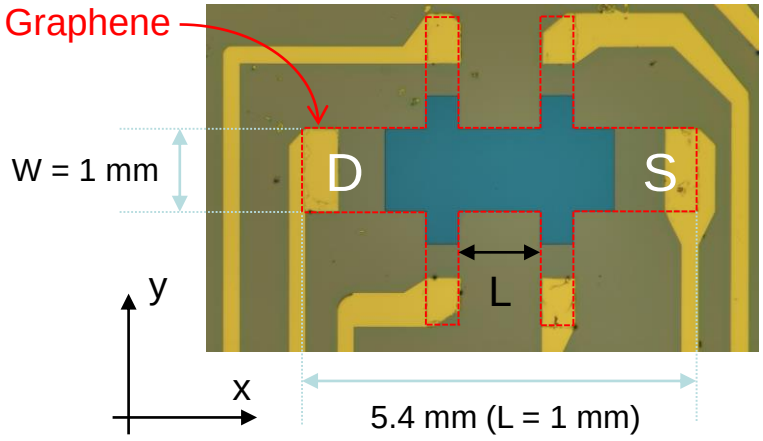
** Hualin Zhan , et. al. *J. Phys. Chem. C*, 121:4760, 2017

Fabrication of graphene Hall structures

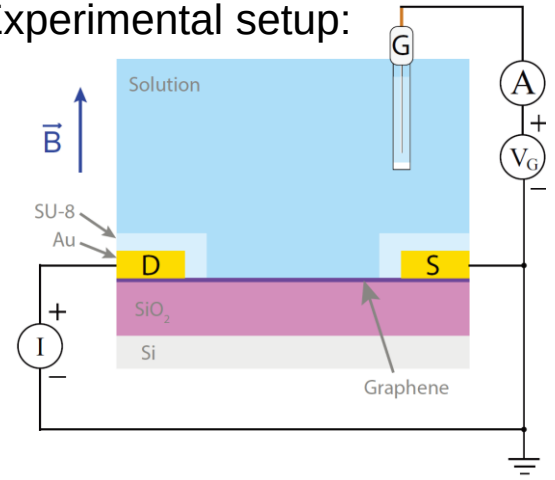
- Hall structures fabrication*



Large area graphene Hall structure:



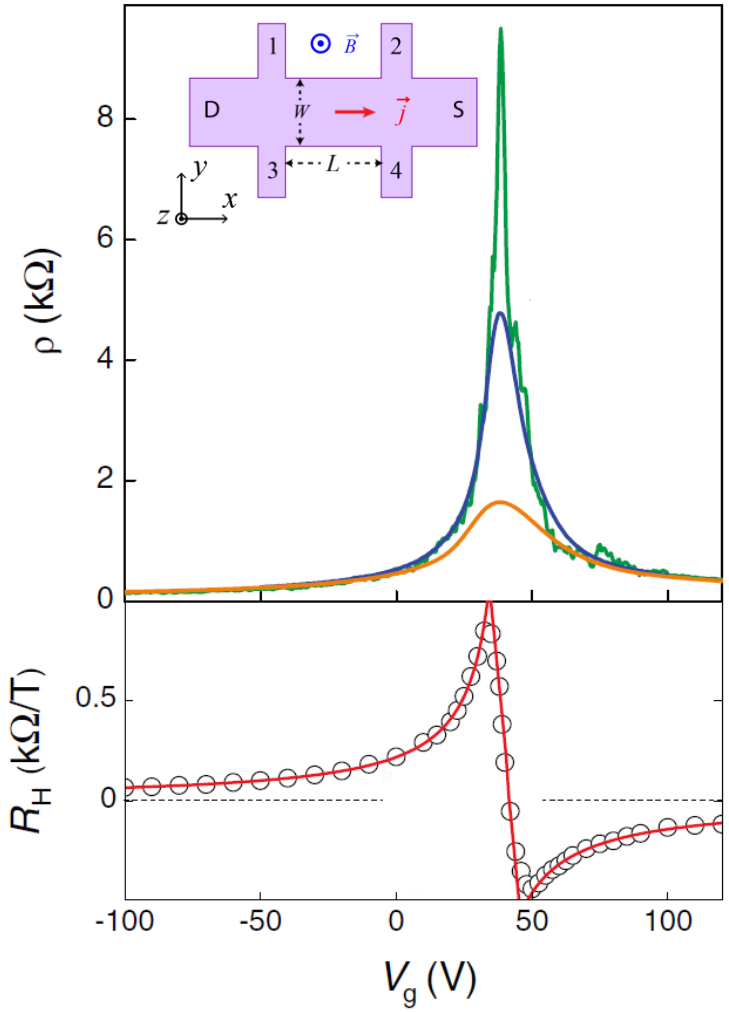
Experimental setup:



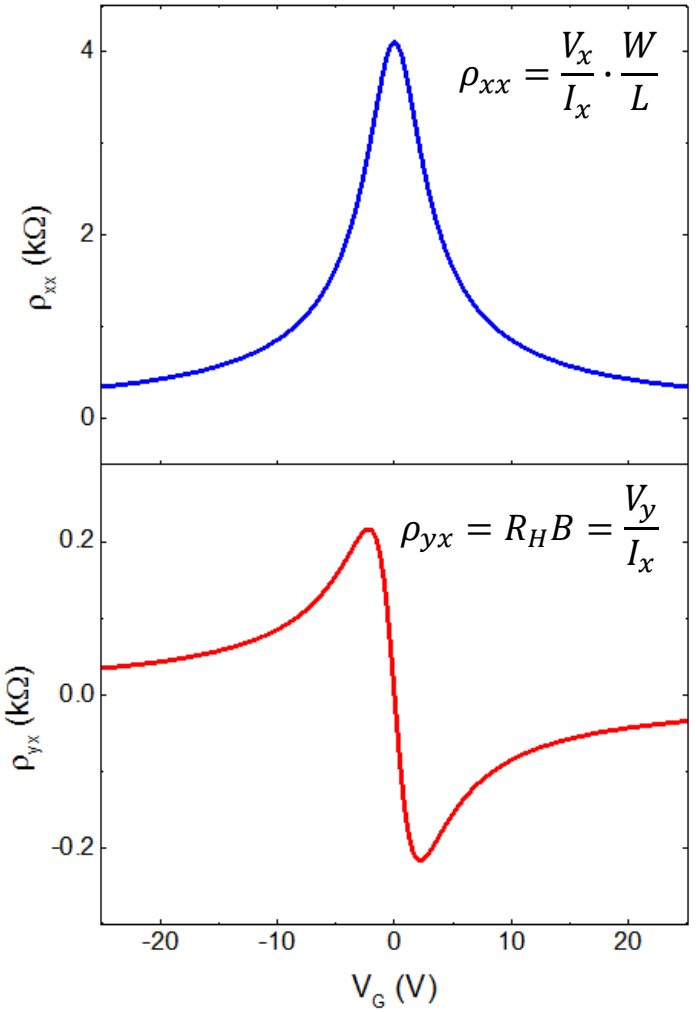
*arXiv:1704.01481

Hall effect of solid-state graphene devices

Experiment*

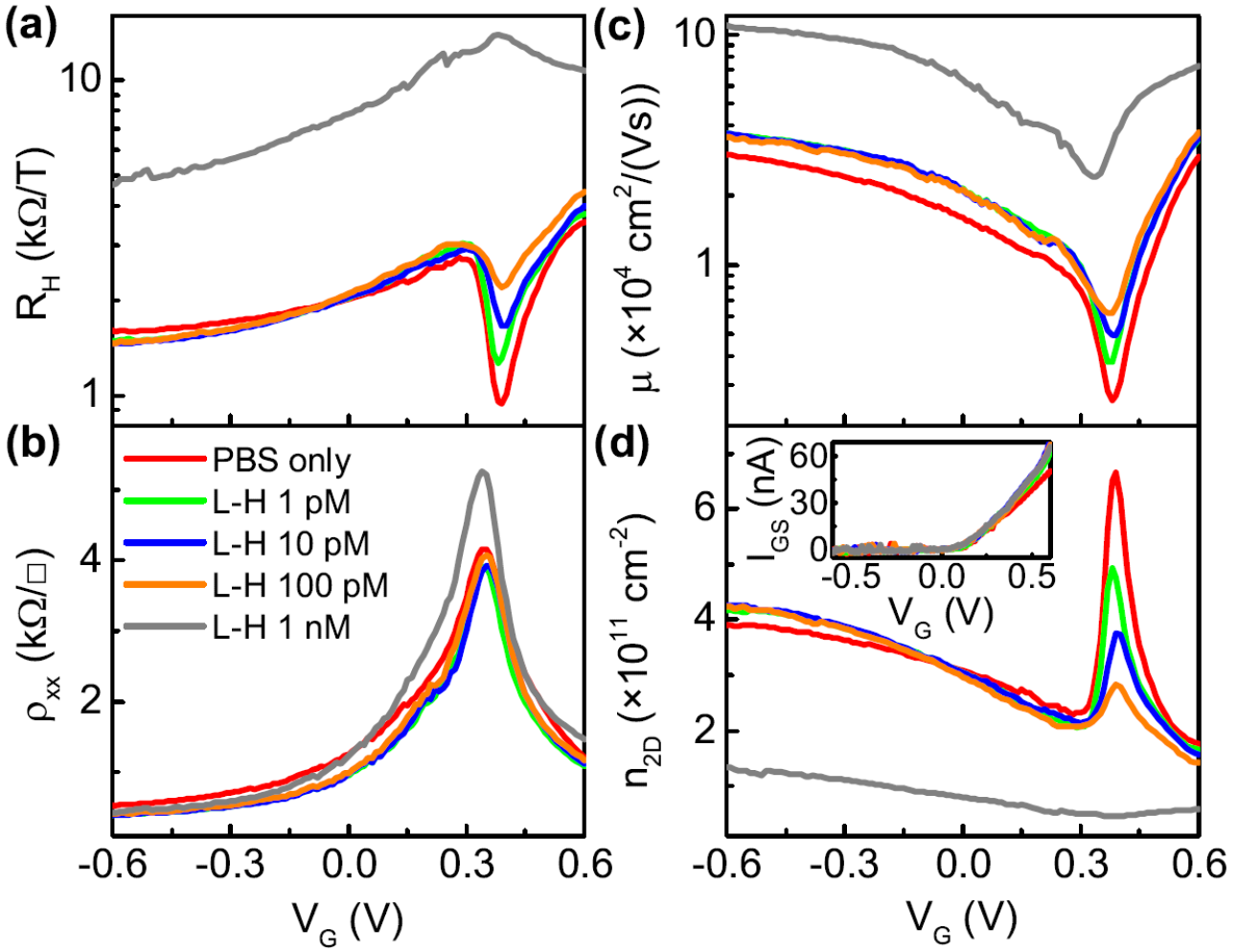


Theory



* K. S. Novoselov , A. K. Geim, et. al. *Science*, 306:666, 2004

Detection of L-histidine in the pM range



$$R_H = \frac{1}{B} \cdot \frac{V_y}{I_x} \approx \frac{1}{|en|}$$

$$\rho_{xx} = \frac{V_x}{I_x} \cdot \frac{W}{L} \approx \frac{1}{en\mu}$$

- No change in ρ_{xx} ⇒ Insensitive for ISFET
- No change in I_{GS} ⇒ Insensitive for CV
- Analysis indicates that n and μ change oppositely
- Changes occur mostly near the 'Dirac' point
- Shape of R_H is significantly different

Asymmetry?

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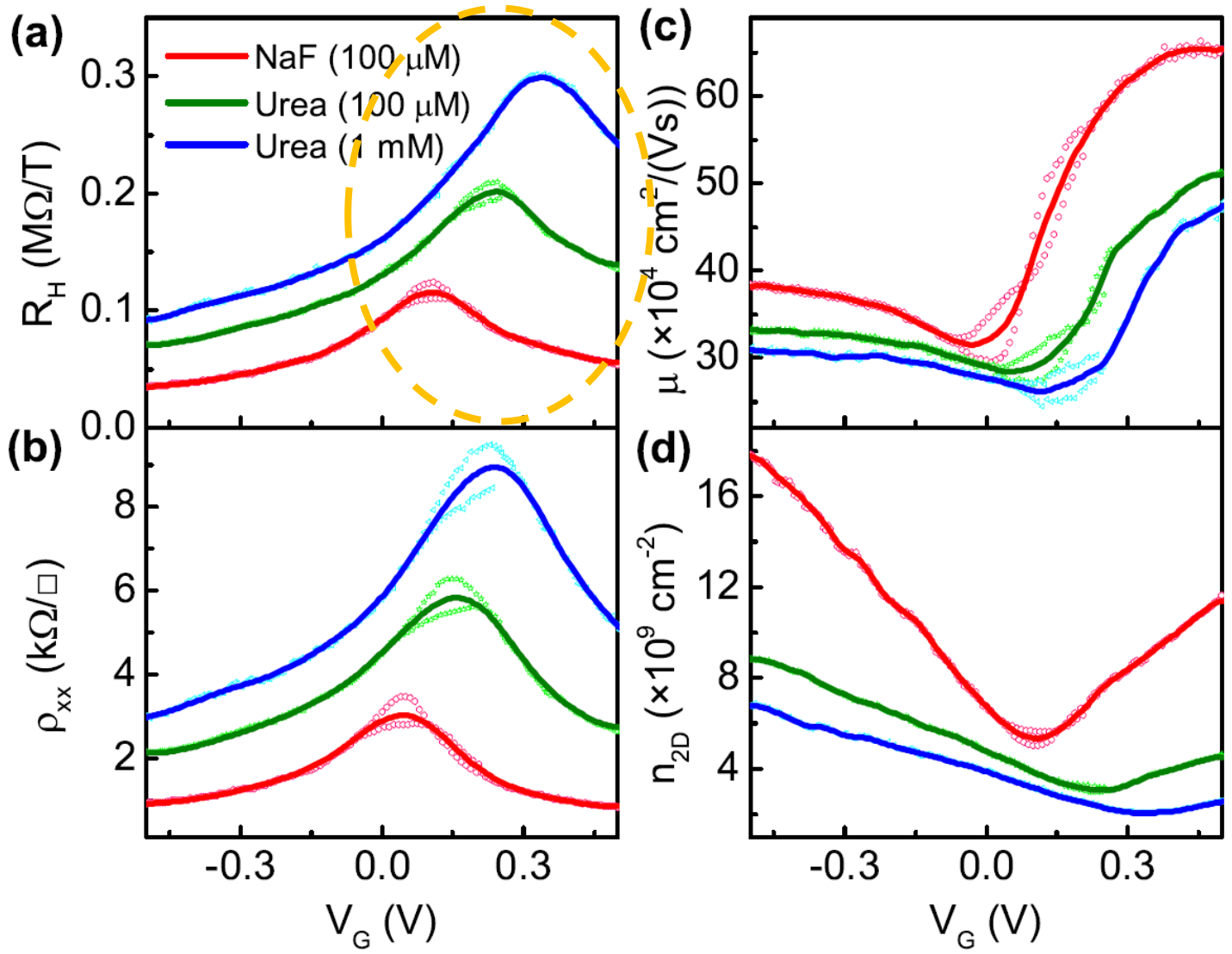
Detection of urea in the mM range



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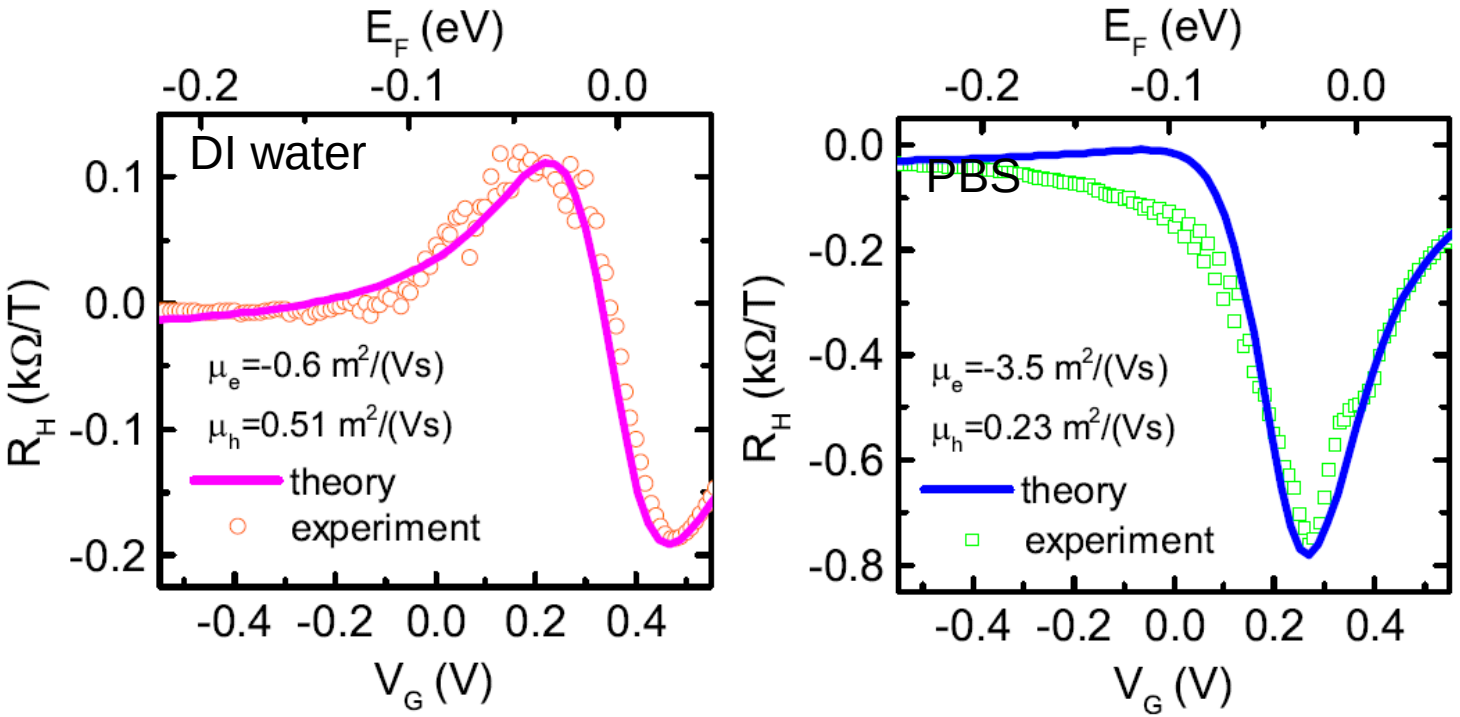
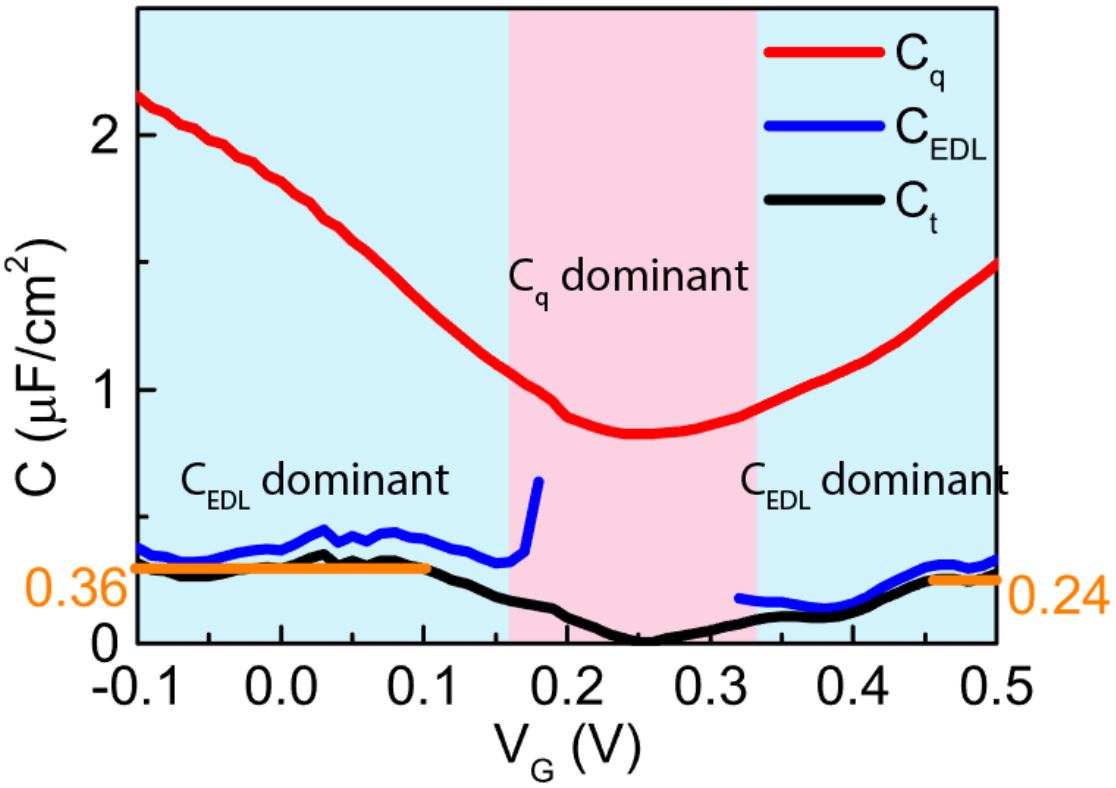
Discussion of the sensing mechanism - 1

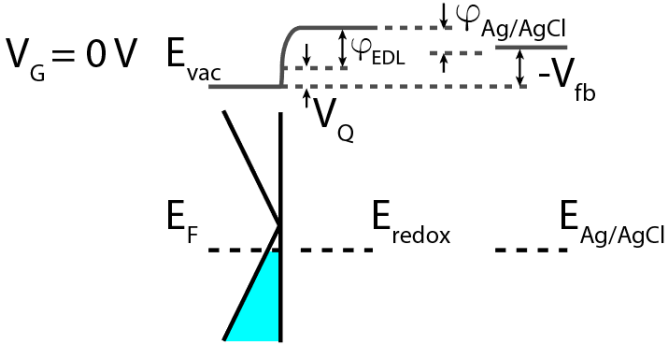
- Hall effects measurement in DI water and PBS



$$R_H = \frac{n_h\mu_h^2[1+(\mu_e B)^2] - n_e\mu_e^2[1+(\mu_h B)^2]}{e[(\mu_e\mu_h B)^2(n_e-n_h)^2 + (n_e\mu_e - n_h\mu_h)^2]}$$

Discussion of the sensing mechanism - 2





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Conclusion

- A very sensitive bio-sensing method is demonstrated by liquid gated Hall effect measurement.
- This technique is more sensitive than amperometric and potentiometric methods in some cases.
- The asymmetric electron-hole mobility induced by the charged impurities in solution helps us to identify the molecules.
- Quantum capacitance of graphene is only dominant near the ‘Dirac’ point in some cases.
- Most importantly, please let me know if anyone is looking for a postdoc, as I’m finishing my PhD. ☺

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Thank you!