Nearly Intrinsic Electron and Hole Transport in Channel Passivated WSe_2 Field-Effect Transistors with Graphene Contacts

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Outline

- Motivation
- Experimental details
- Results
- Conclusion

Motivation

TMD

Transition Metal Dichalcogenides

- Ultra-thin and uniform channel
- Surface smoothness
- Mechanically flexible and strong.
- Thermally stable
- Reasonably good mobility
- WSe_2 large hole mobility

Challenge:

- Significant Schottky barriers at metal/WSe_2 contacts for both the electron and hole channels

Contact engeering:

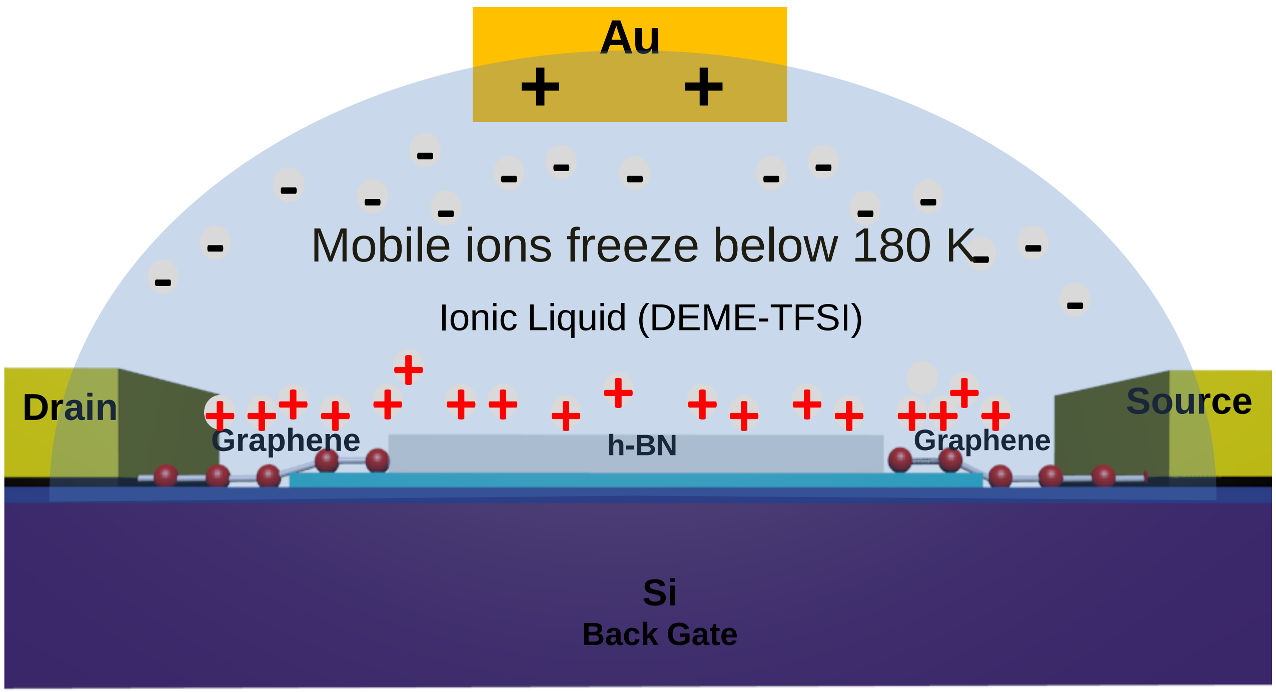
- Electrostatically dope graphene contacts by an Ionic Liquid gate
- Air-Stable Surface Charge Transfer Doping of graphene contacts (BV and F4-TCNQ)

To preserve the intrinsic channel properties

- h-BN Encapsulation of the WSe_2 channel

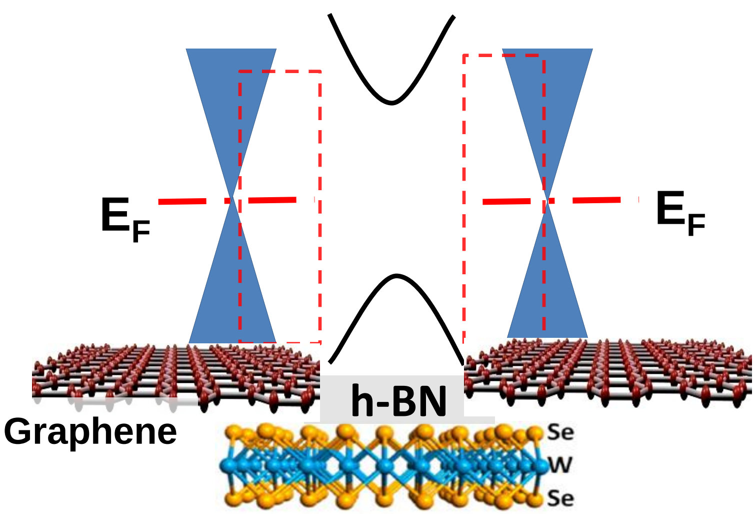
WSe_2 FET with IL gated graphene contacts

- Ionic Liquid gating



H- J Chuang, et al., Nano Lett. 2014

WSe_2 FET with IL gated grapehene contacts



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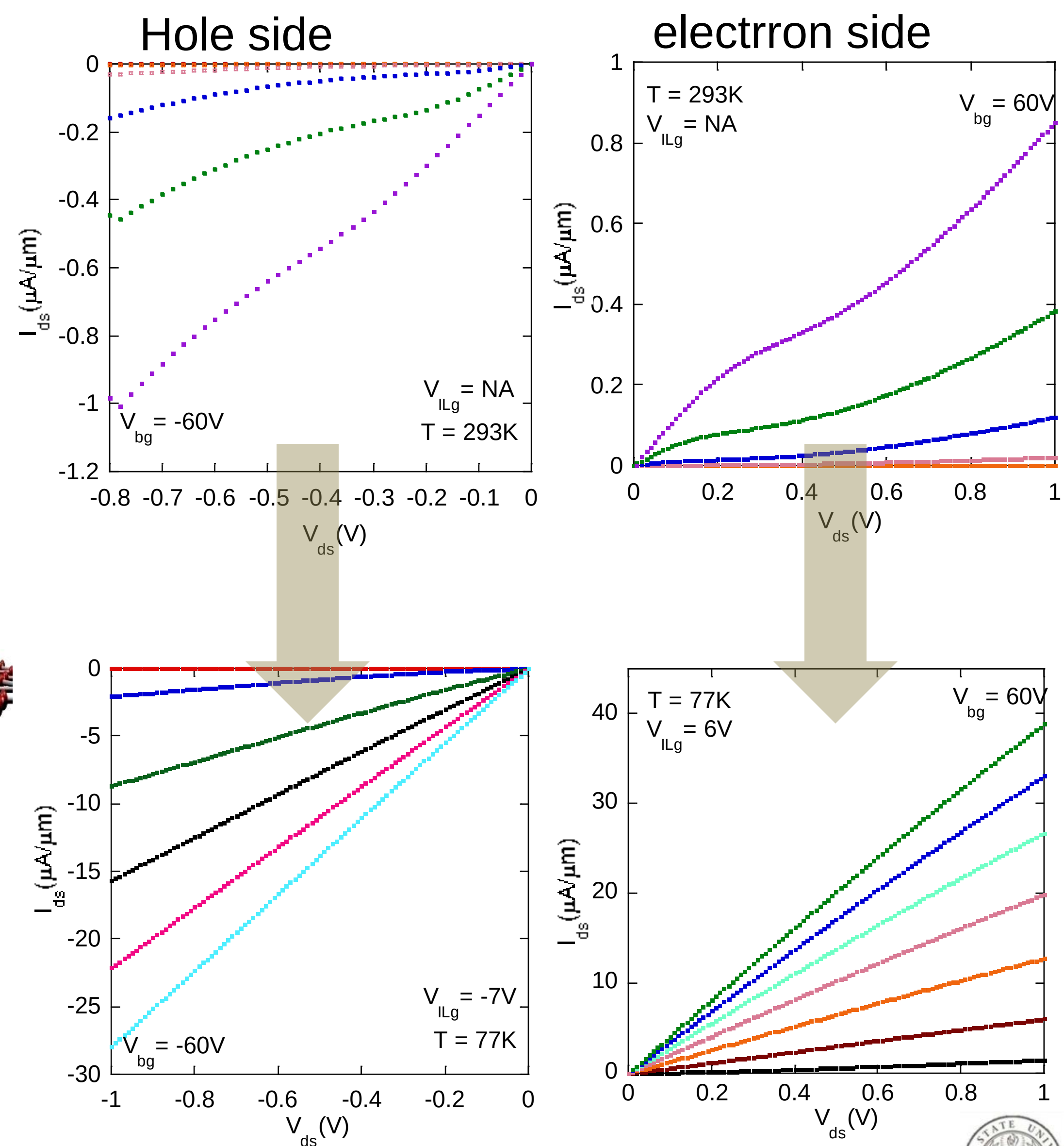

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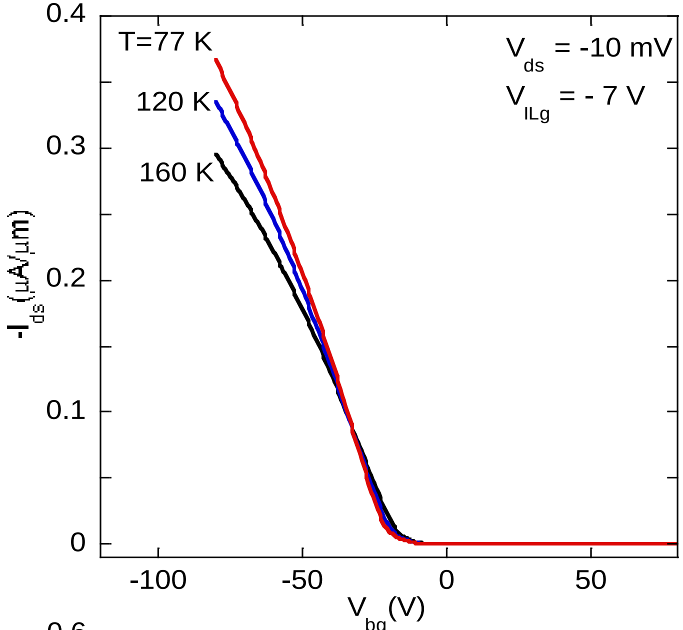
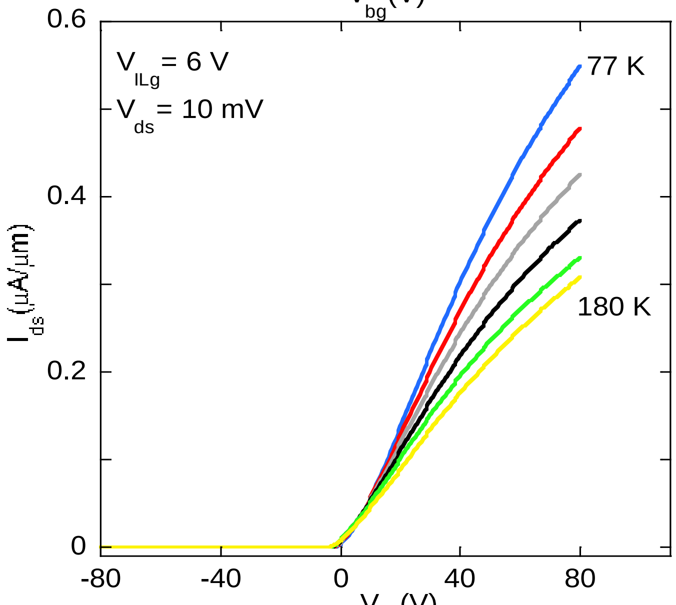
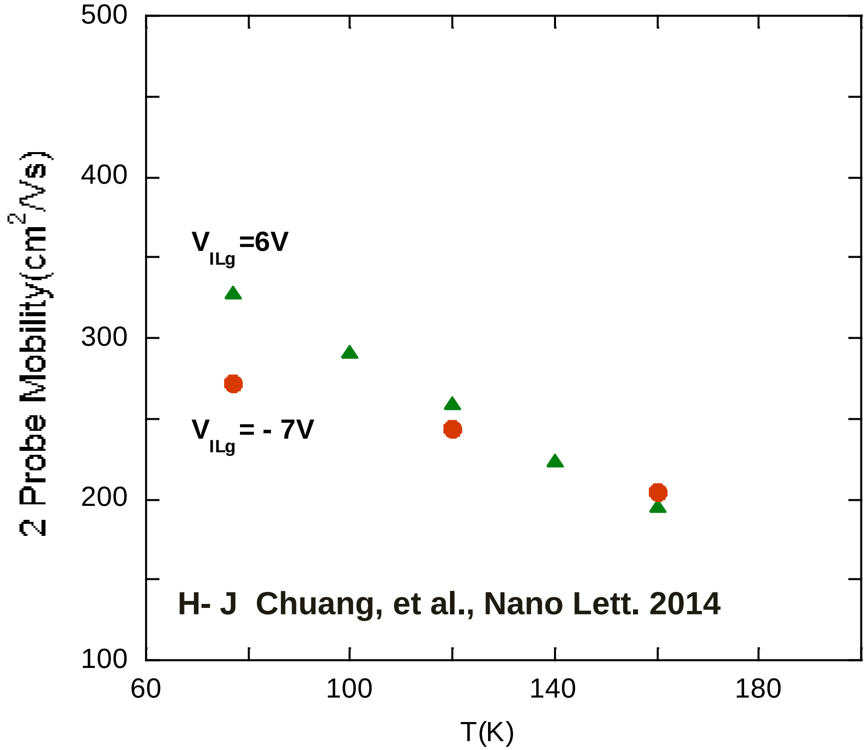






Two-probe field-effect mobility for both electrons and holes:

➢ relatively large

➢increase with decreasing temperature, indicating intrinsic phonon limited channel behavior

Improvement method

Contact engeering

Goal: low resistance Ohmic contacts

- Ionic liquid gating
  Good as a proof of principle, but not suitable for the real applications

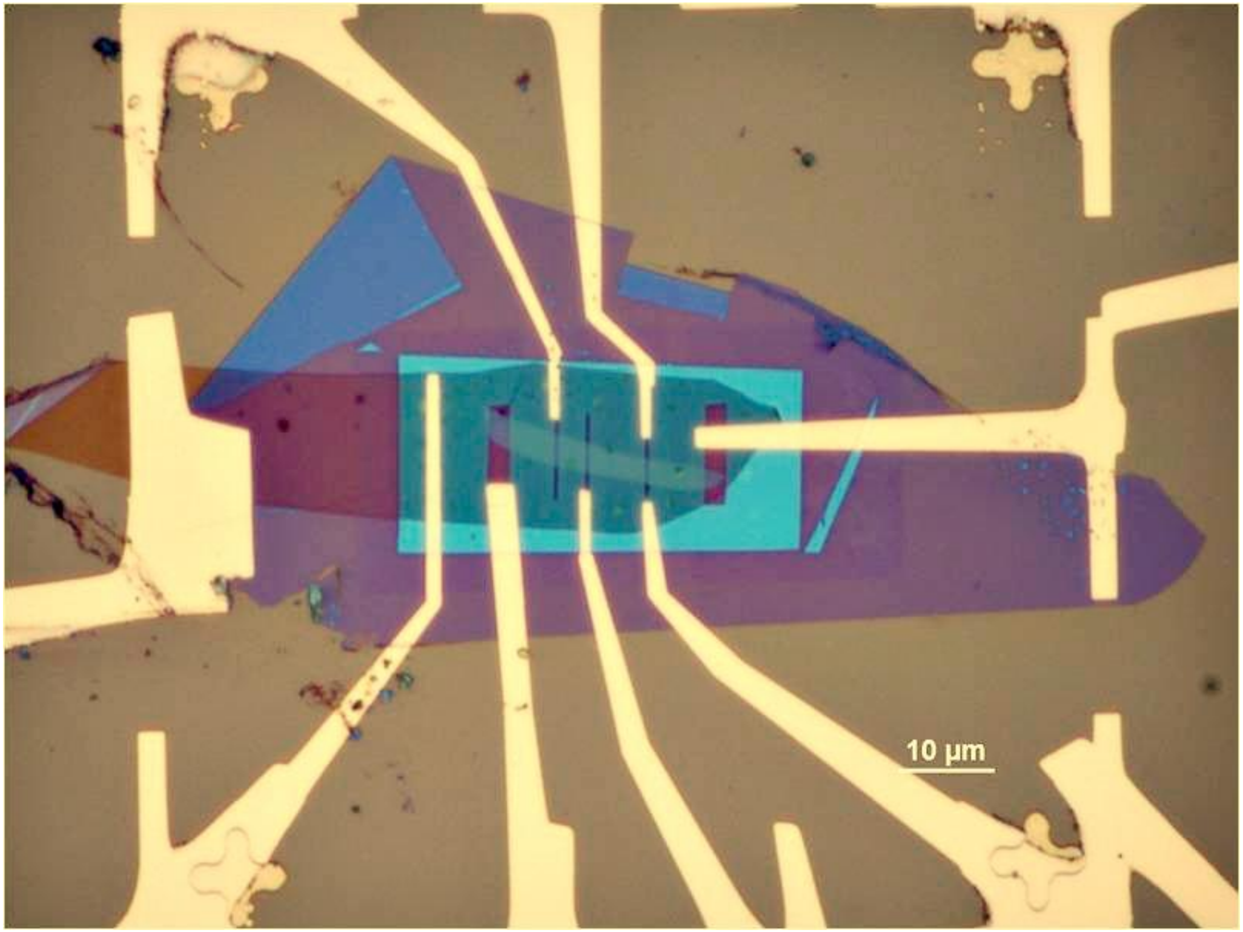
- Air stable molecular surface charge transfer doping of graphene contacts

  - Strong electron donor BV (Benzyl Viologen) for Electron doping
  - Strong electron acceptor F4-TCNQ for hole doping

Intrinsic transport properties and performance limit of WSe2 as a channel material

- Encapsulate the WSe_2 channel with h-BN to minimize the scatterings from the interface and substrate/dielectric

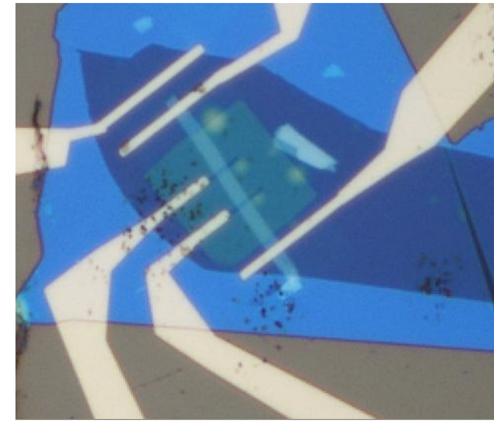
Device Fabrication

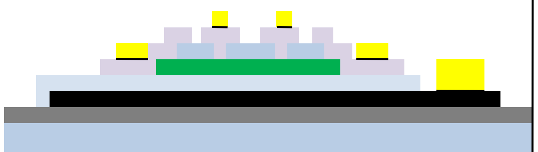


Device Fabrication

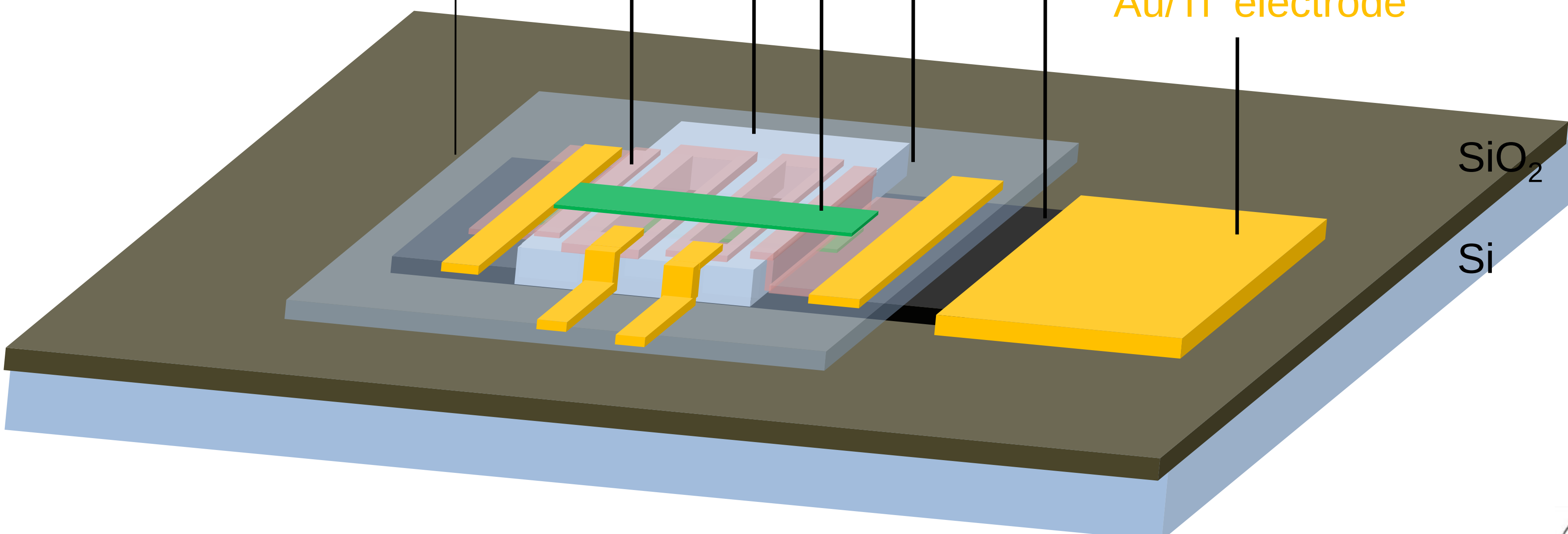
Where C_{bg} is determined to be 6.9×10^{-8} F cm^{-2} for 45nm hBN based on the parallel capacitor model ($C_{bg} = 3.5\varepsilon_0 / 20nm$)

WSe_2 channel :
Length~ 13um /3.7um
Width ~1.6um
Thickness ~3.2nm

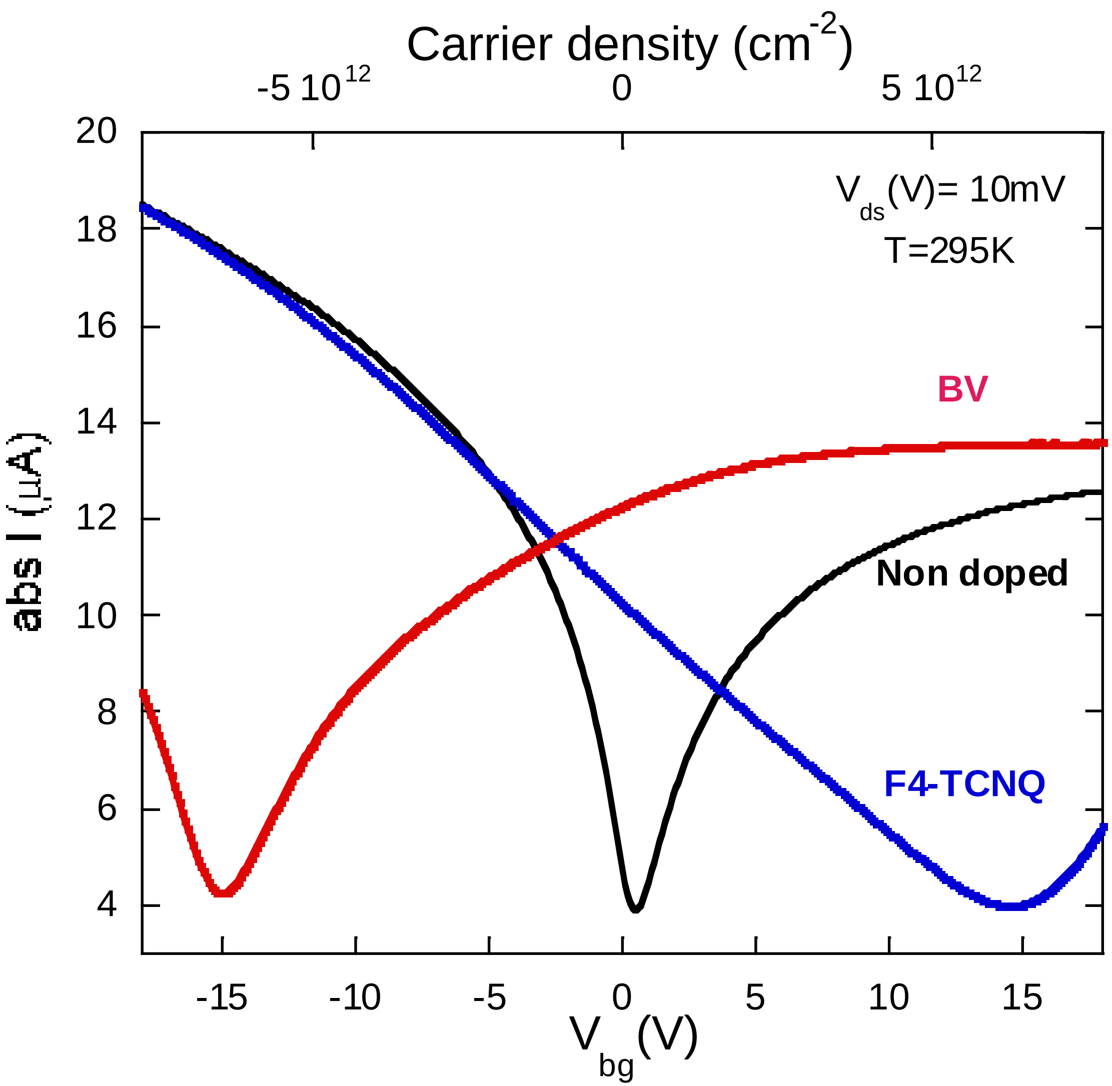




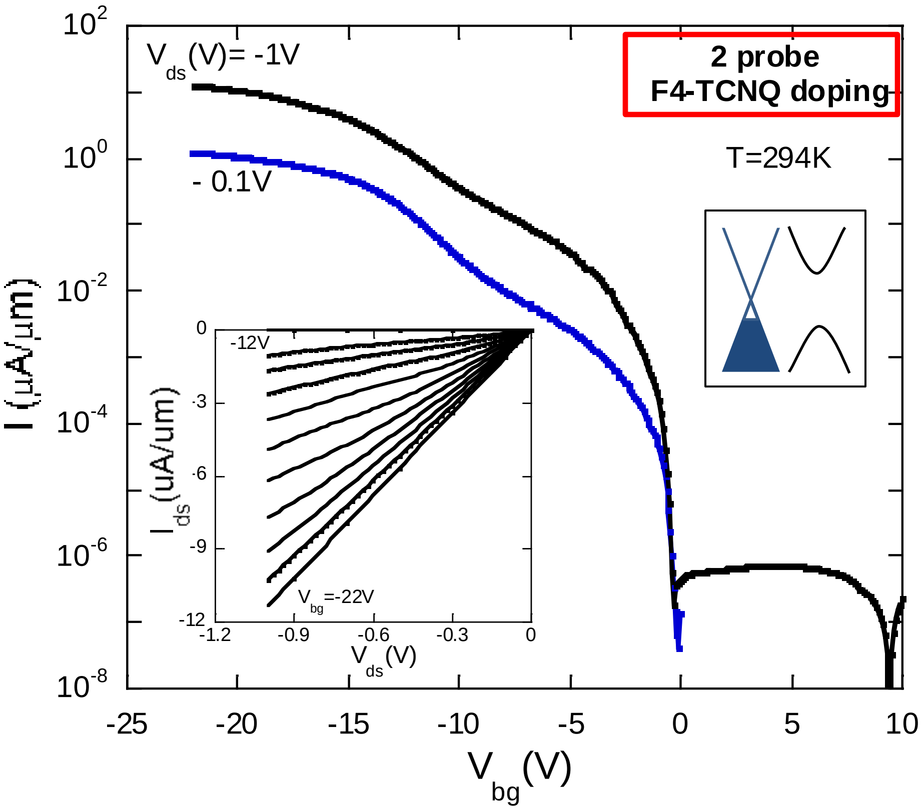
Cross section

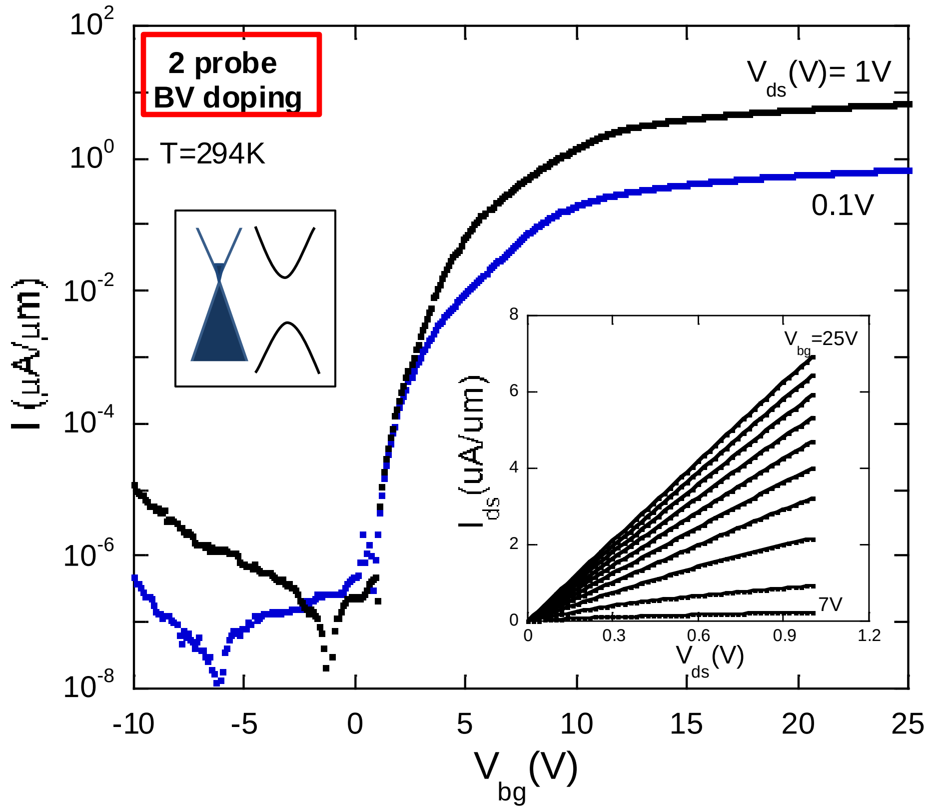


Molecular doping of graphene



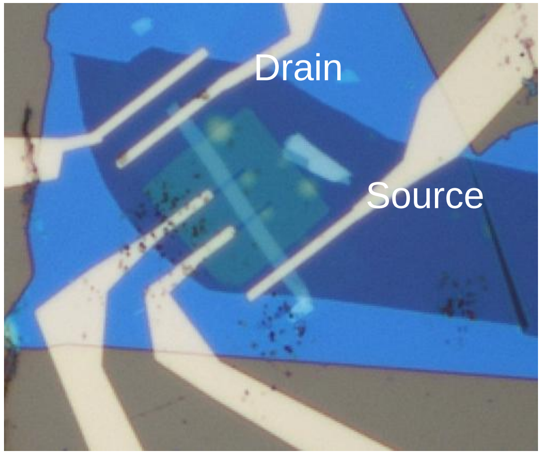
2 Probe Transfer and Output Characteristics of WSe_2

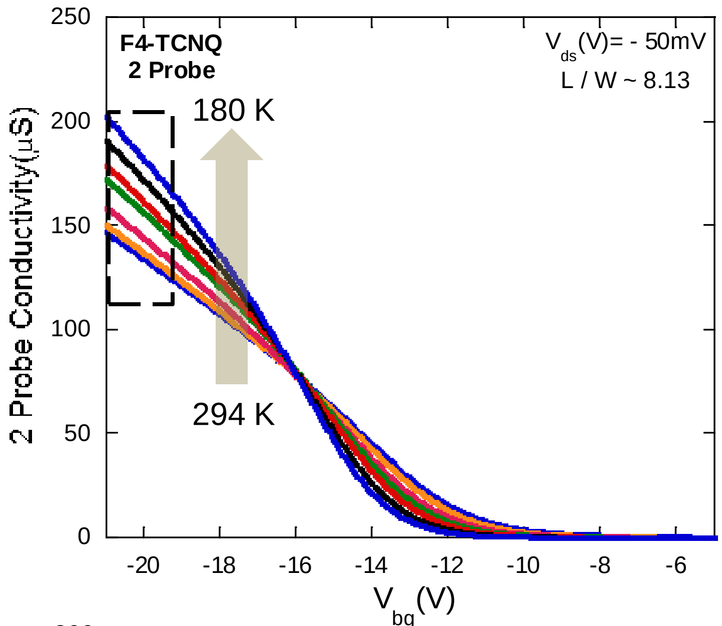


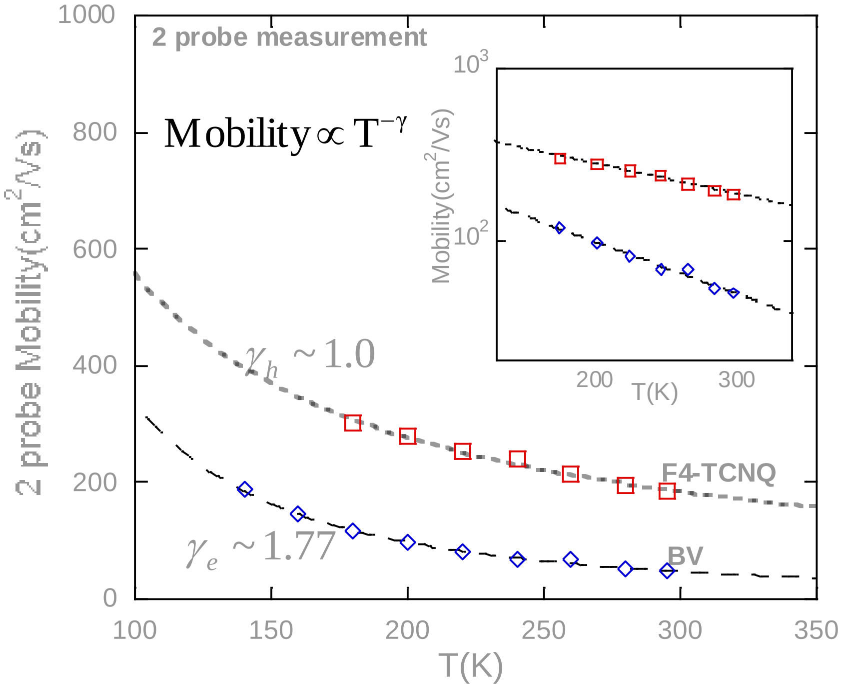


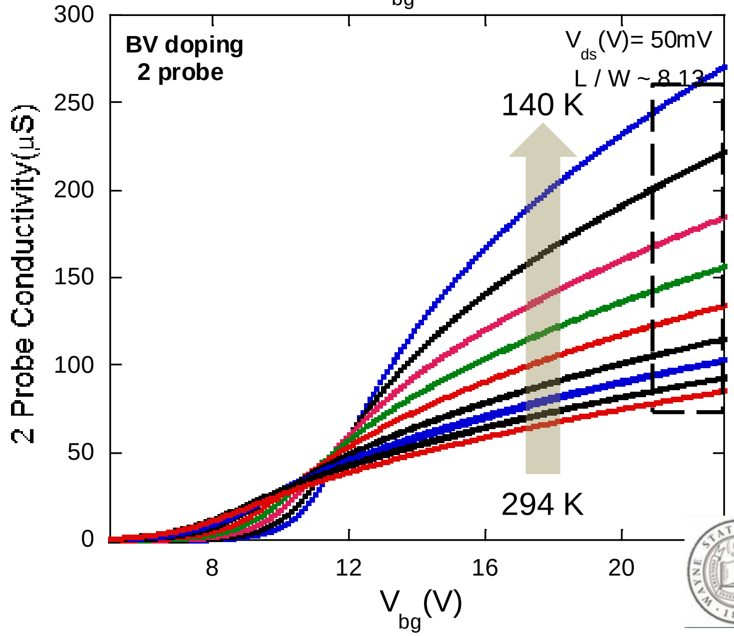
- ***Device Performance : On/Off ratio > 10^7***
- ***Linear IV characteristics → near Ohmic contacts***

2 Probe Transfer Characteristics

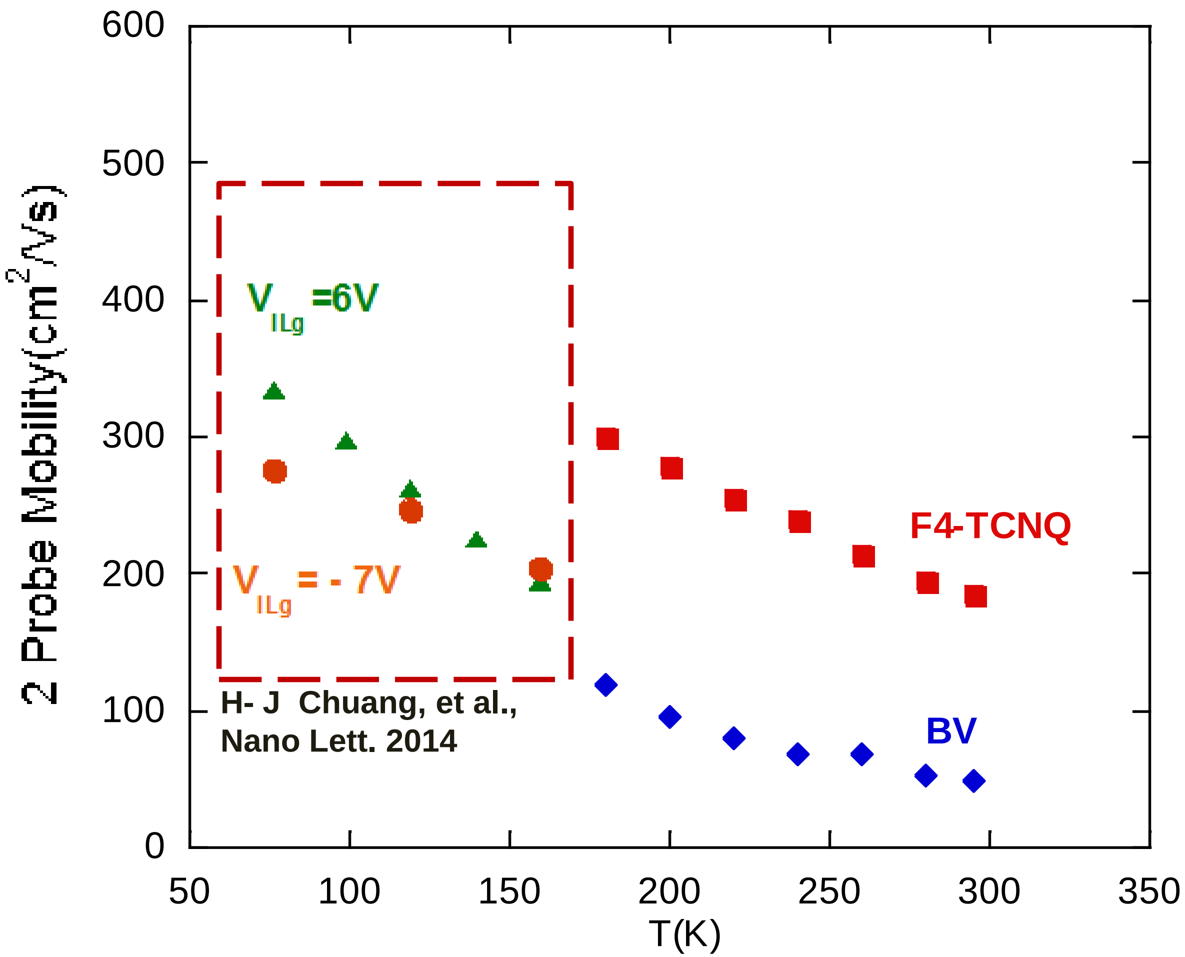




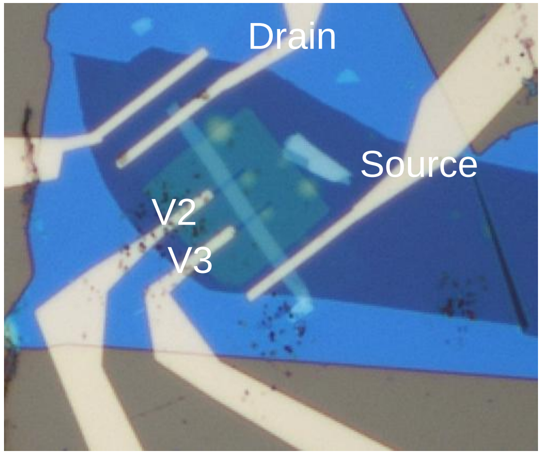


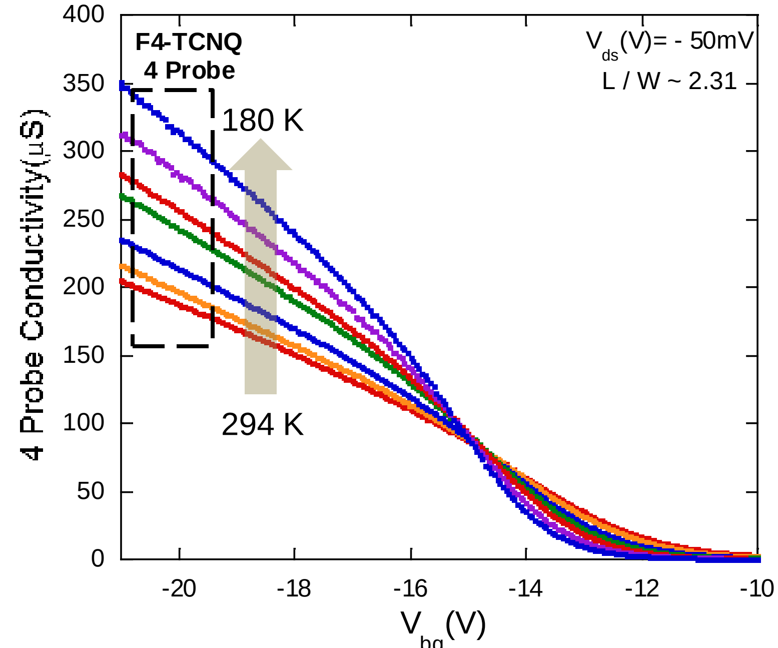


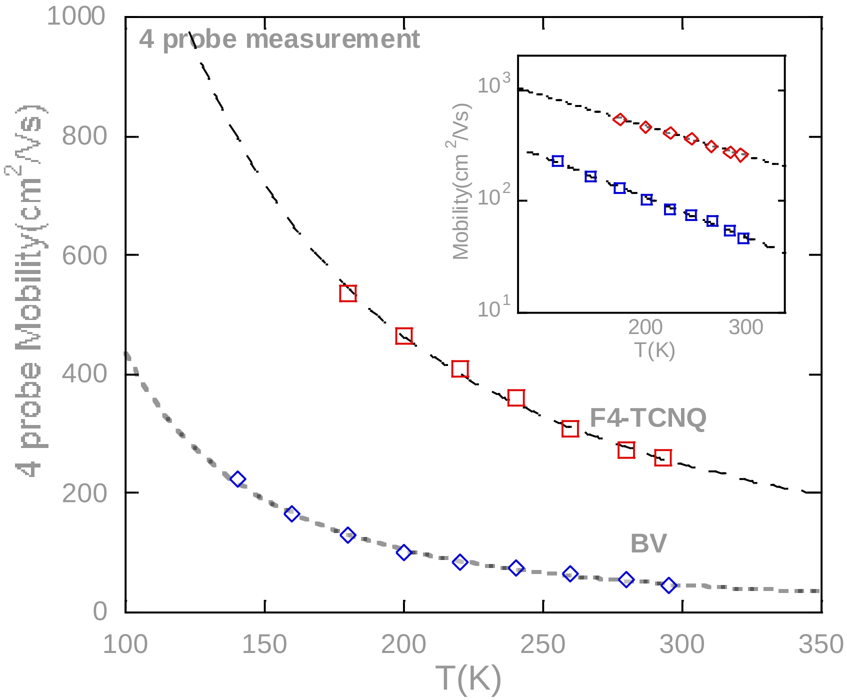
➢Comparison of molecular doping and ionic liquid gating in improving Graphene contacts

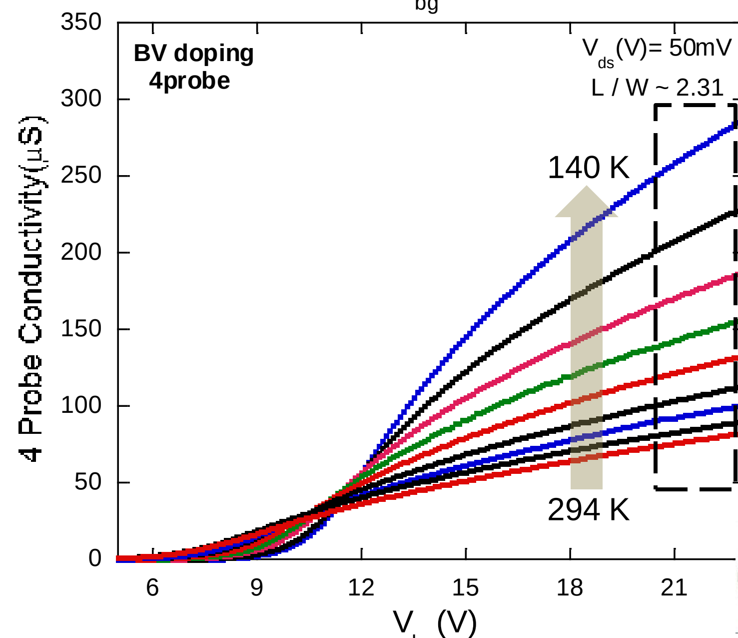


4 probe transfer characteristics









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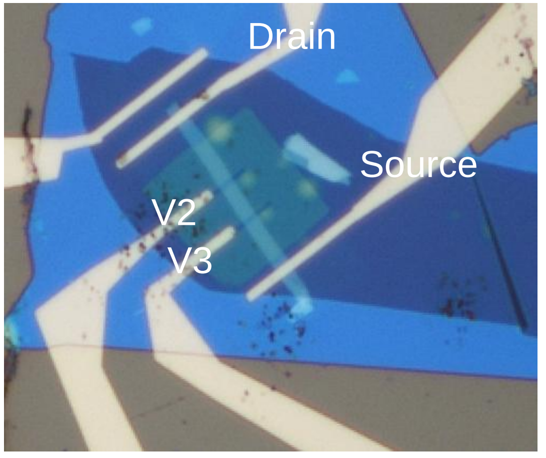
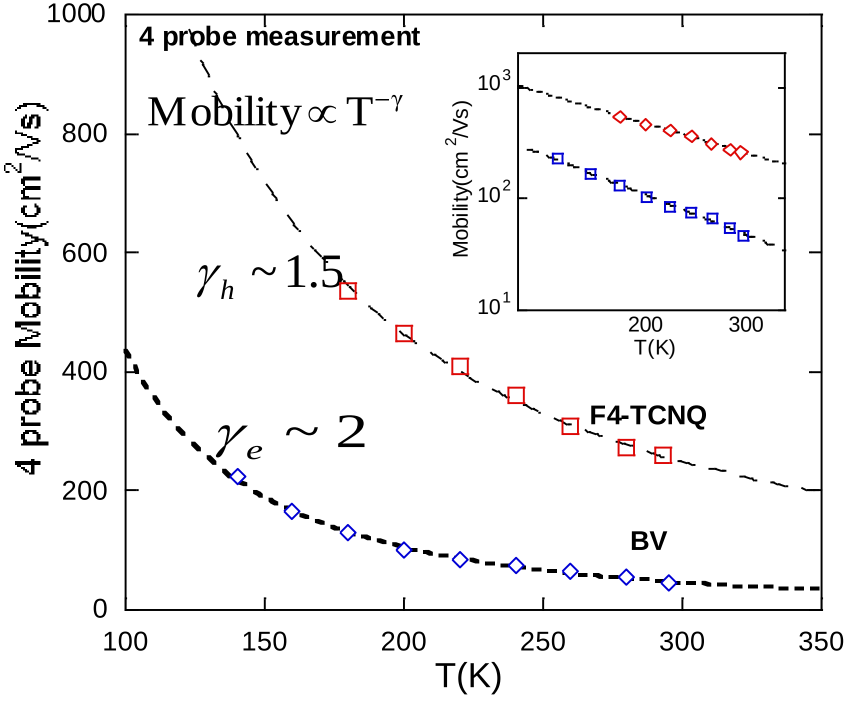


- ➢RT hole mobility: 258 cm^2/Vs
- ➢RT electron mobility: 46.5 cm^2/Vs

- $m_h \sim 0.3 \pm 0.2\ m_0$
- $m_e \sim 0.9\ m_0$

Klein, A., et al. *Solar materials and solar cells*, 1997*energy*



➢γ_e~ 2.0 (and RT electron mobility)

similar to hBN encapsulated MoS_2
(Perera talk and Xu Cui et al.
http:// arxiv.org/abs/1412.5977)

➢ γ_h ~1.5

Suggest possibly different scattering mechanisms

Conclusion

- Achieved nearly Ohmic contacts for both electrons and holes in WSe_2 FETs by using molecular doping of graphene contacts

- Observed nearly intrinsic electron and hole mobility limited by phonon scattering in hBN encapsulated WSe_2

- Difference in electron and hole mobility may be attributed to the different effective mass and scattering mechanisms for electrons and holes in WSe_2

Acknowledgment

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