Center for Energy Efficient Electronics Science

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Chemically Doped Graphene Contacts for n- and p-type WSe_2 Transistors

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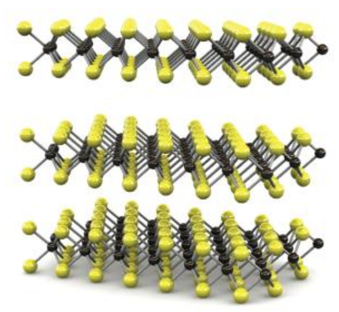
Motivation

2D Materials

- Atomically thin
- No broken/dangling bonds on surface[1]
- Tunable band gap (composition and layer number)
- Advantageous mechanical properties

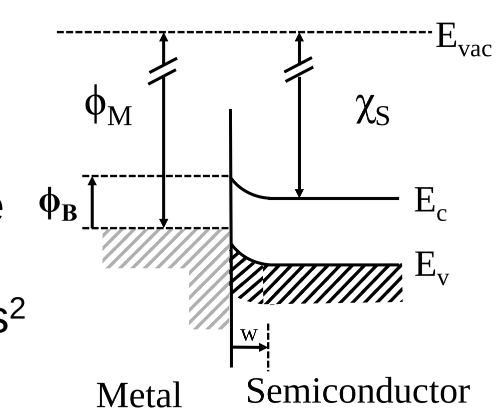


Wang, Q.H et al. *Nature Nanotech.* **2012,** 7, 699-712

Schottky Barrier

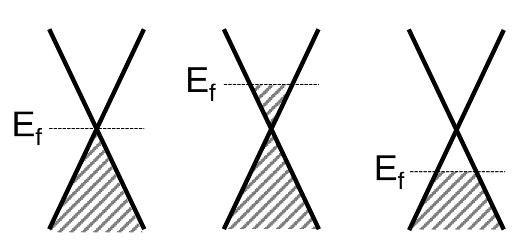
$$\phi_B = \phi_M - \chi_S$$

- SB increases contact resistance and limits device performance
- Major problem for WSe_2 devices[2]



Graphene Contacts

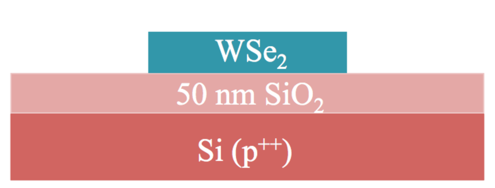
- Eliminates interface trap states
- Tunable work function with adsorbed molecules
  - BV (n-type)
  - NO_2 (p-type)



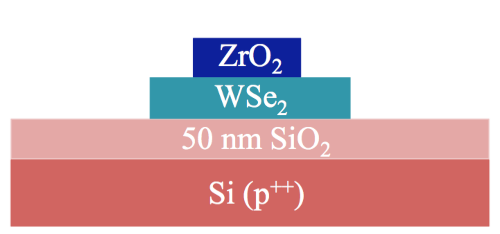
Project Goal : Reduce SB height in n- and p-type WSe_2 transistors

Device Fabrication

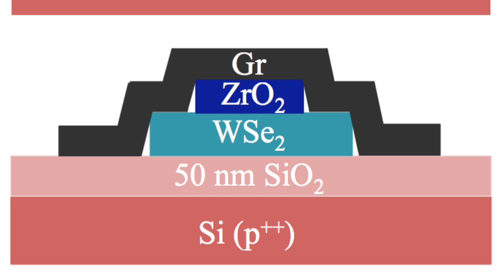
Step 1: Mechanically exfoliate WSe_2 flake and etch using EBL



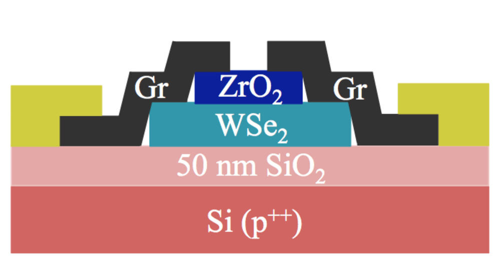
Step 2: Pattern and deposit oxide for channel protection



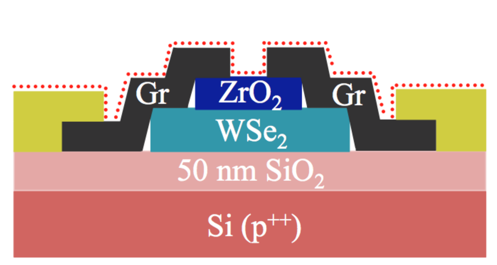
Step 3: Dry transfer of graphene flake



Step 4: Etch graphene and evaporate metal contacts



Step 5: Dope with BV/ NO_2

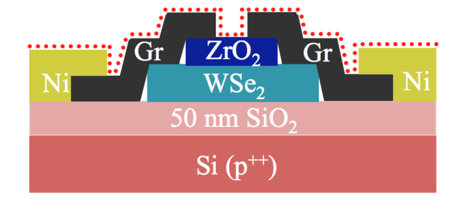


Abstract

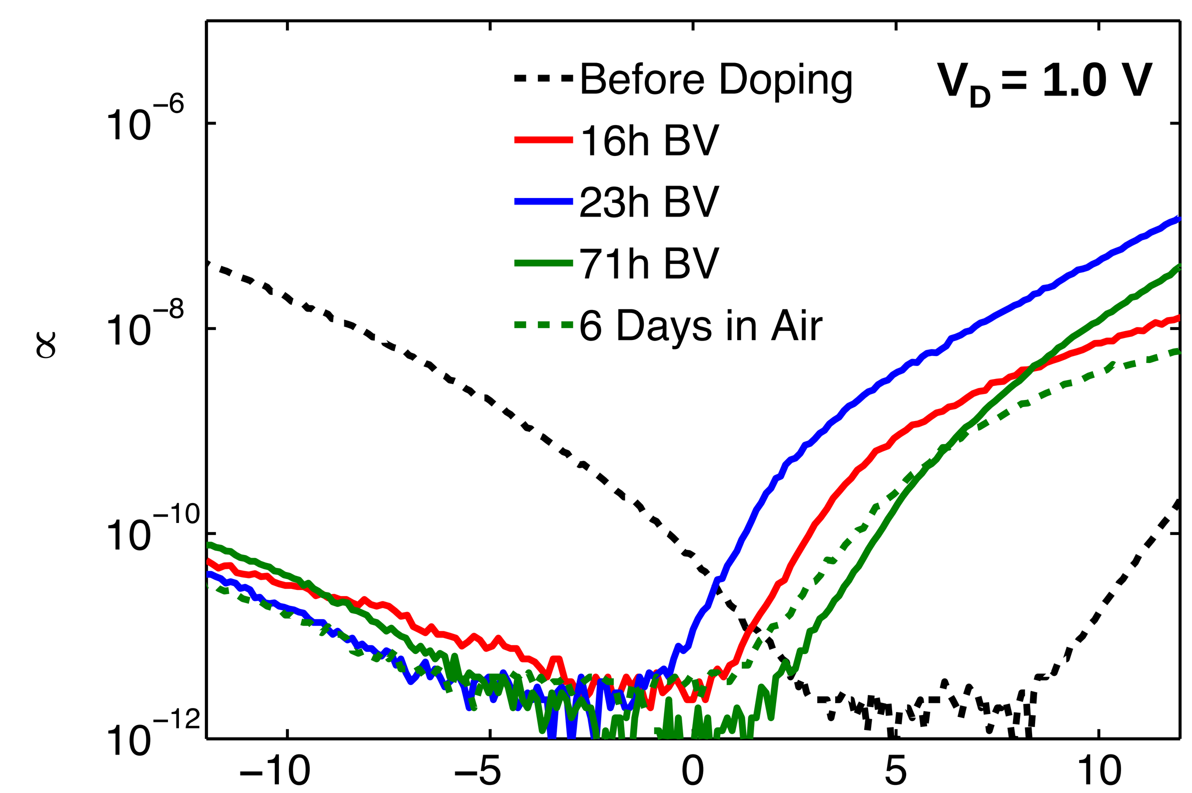
Chemically doped graphene was used to fabricate n-type and p-type transistors using WSe_2 as the channel material. Benzyl Viologen (BV), a strong electron donor, was used as the n-type dopant allowing graphene to contact the WSe_2 valence band. BV doping graphene was shown to give n-type behavior in WSe_2 that initially showed ambipolar characteristics by increasing (decreasing) electron (hole) current by 1000x and reducing Schottky barrier height. NO_2, an electron acceptor, was used as the p-type dopant for graphene. NO_2 doping was shown to penetrate the protective oxide on the channel to give degenerate doping of the WSe_2. In both cases the dopants are shown to be air stable.

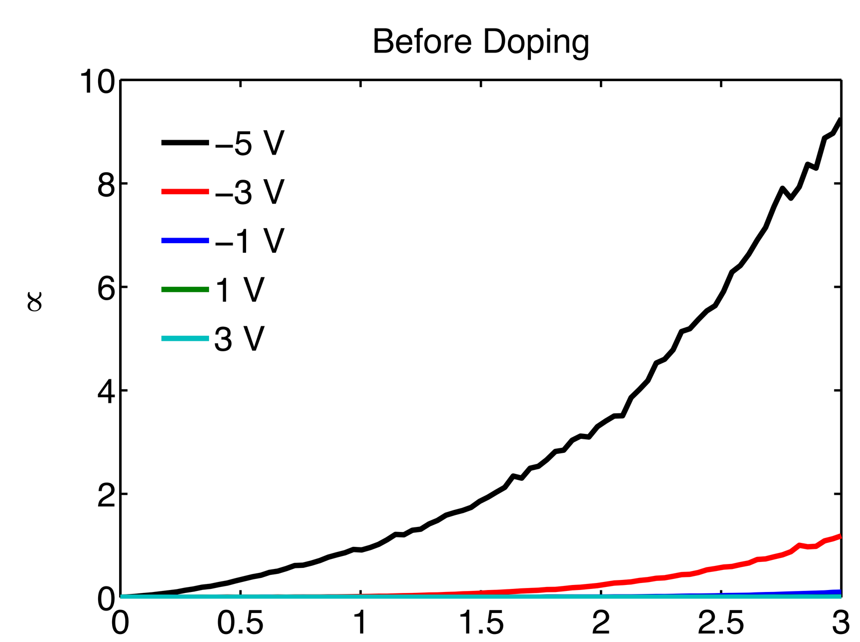
BV Doped Device Performance

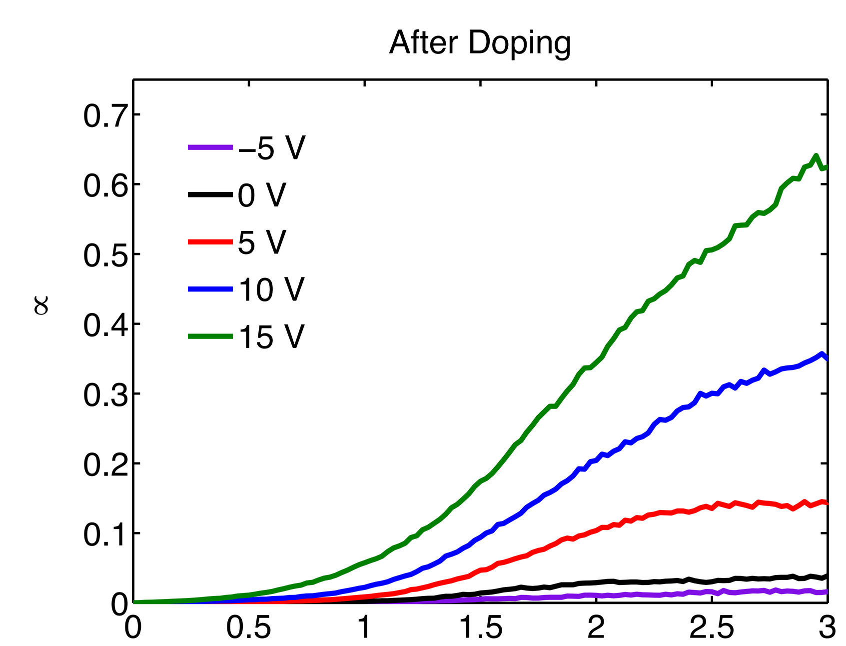
Device Characteristics



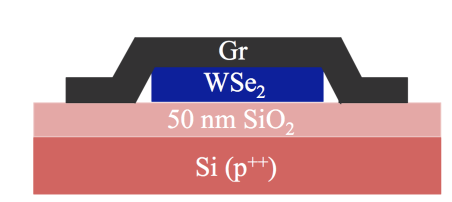
- 1000x decrease in hole current
- 1000x increase in electron current
- V_T shift negative
- Air stable
- SB reduced
- Channel undoped

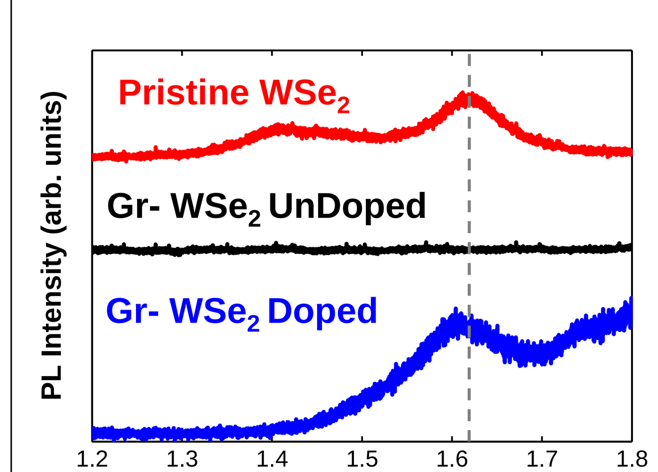


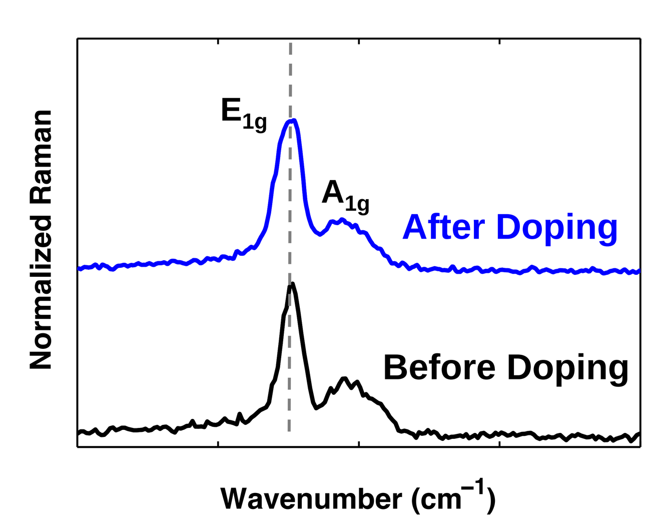


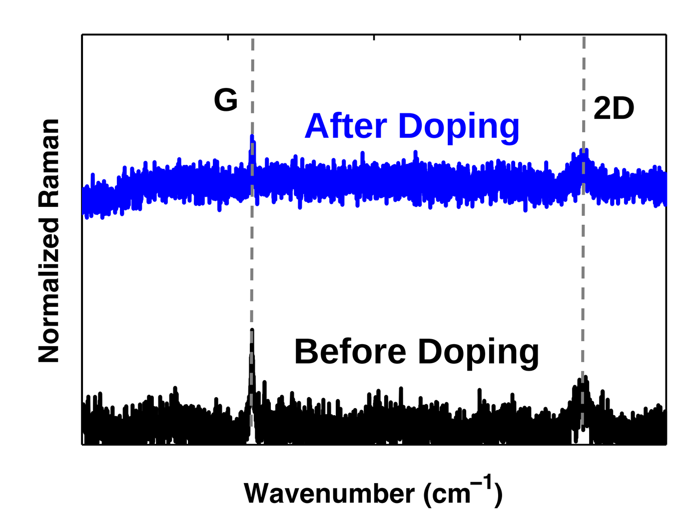


PL / Raman Characterization





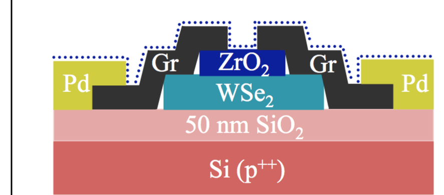


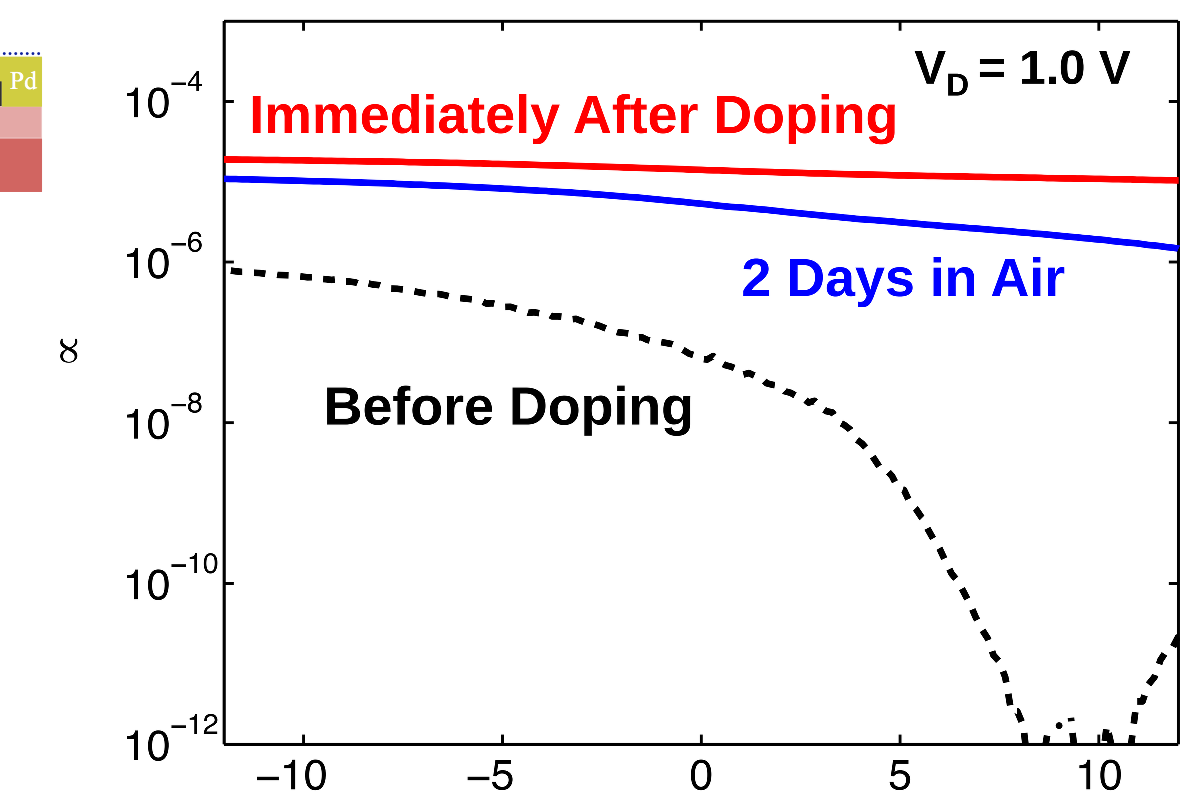


- Regain 1.6 eV peak after doping
- Lose 1.4 eV peak
  - Result of ET from BV to WSe_2

- No peak shifts indicates doping is local and lattice is pristine. Less carrier scattering

NO_2 Doped Device Performance





- Degenerate p-type performance
  - Channel doped by NO_2
- Air stable

Conclusions / Future Work

WSe_2 n-type transistors were demonstrated with air stable BV doping. Schottky Barrier height was reduced in addition to 1000x increase (decrease) in electron (hole) current. Control experiments showed degradation of the graphene-WSe_2 interface so future work would involve investigating the BV doping mechanism in an effort to protect the interface. The NO_2 device showed air stable, degenerate p-type performance due to channel doping. Future efforts will concentrate methods for protecting the channel as well as investigating the transfer of doped graphene.

References

[1]Wang, Q.H.; Kalantar-Zadeh, K.; Kis, A.; Coleman, J.N.; Strano, M. *Nature Nanotech.* **2012,** 7, 699-712

[2]Fang, H.; Chuang, S.; Chang, T. C.; Takei, K.; Takahashi, T.; Javey, A. *Nano Lett.* **2012**, 12, 3788-3792.

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