Edge Transport Channel on Graphene Nanoribbons

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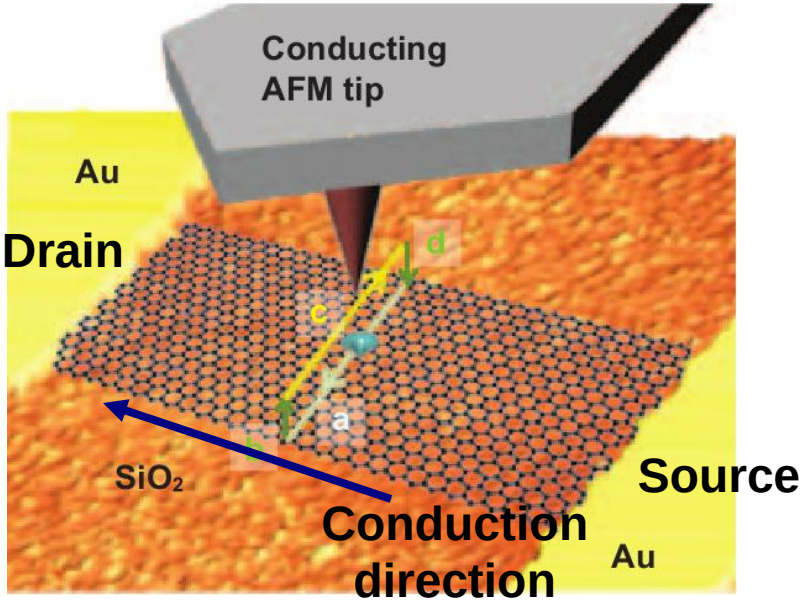
In collaboration with

Jungseok Chae , Y Kuk, SNU

S. Jung, Y. Song, N. B. Zhitenev, J. A. Stroscio, NIST

Motivation

- SGM (Scanning Gate Microscope)



- Measure the conductance (current) as a function of the position of an applied local tip potential (local top gate).

- Probes carrier scattering from impurities, single electron charging effects, quantum confinement, coherent electron flows.

Motivation

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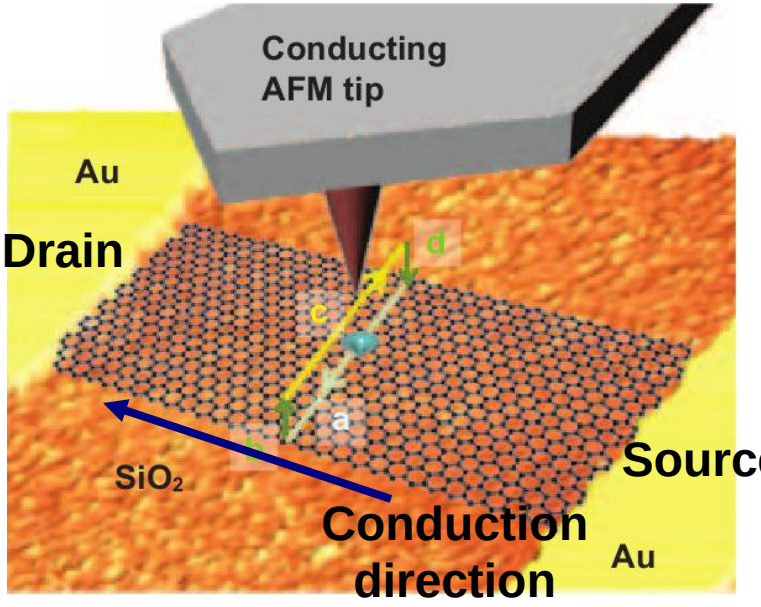
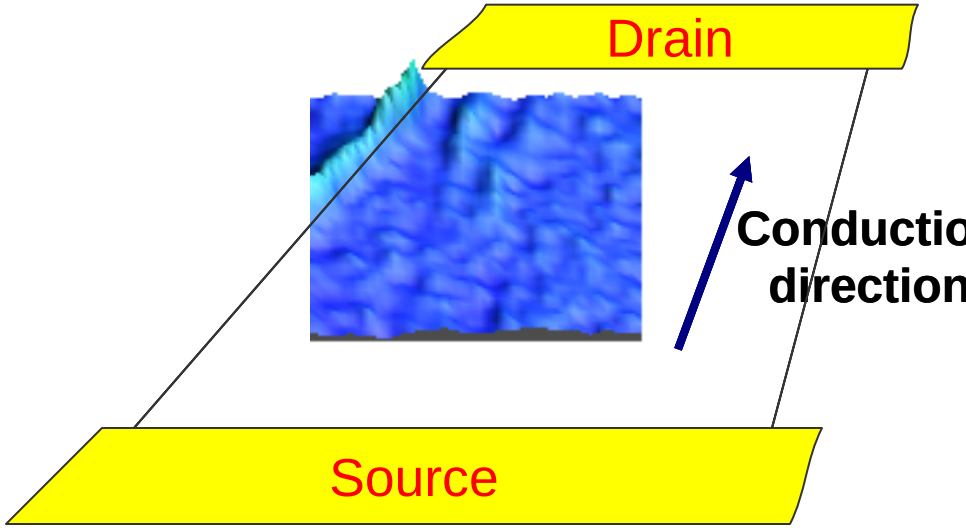


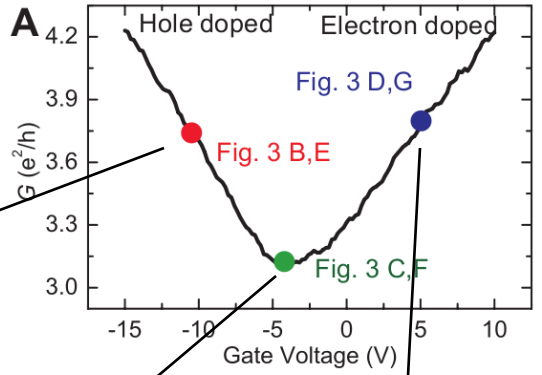


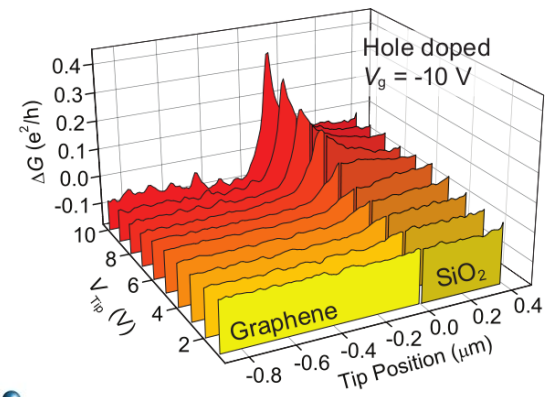
- Edge conductance enhancement occurs on a ***doped GNR*** only when the ***tip potential is against the overall doping***.

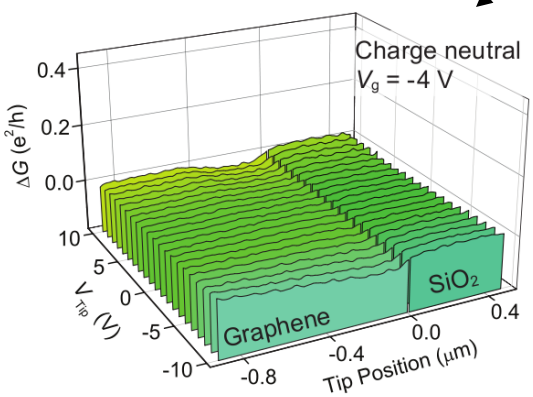
Motivation

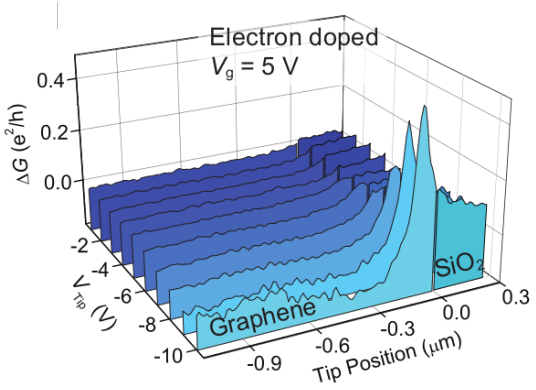
- SGM (Scanning Gate Microscope)
- Edge conductance enhancement occurs on a ***doped GNR*** only when the ***tip potential is against the overall doping***.

I-V curve for back gate charge neutrality point: V_g=-4V









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Theoretical Methods

- Tight-binding Hamiltonian
  - Single π-orbital for each carbon atom
  - Nearest atom hopping interaction
  - On-site energy variation for local potential

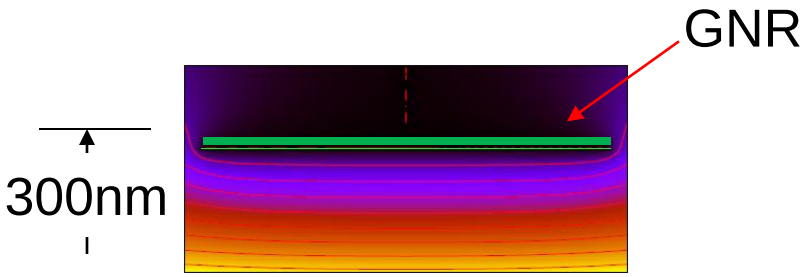
- Transport: Scattering state approach

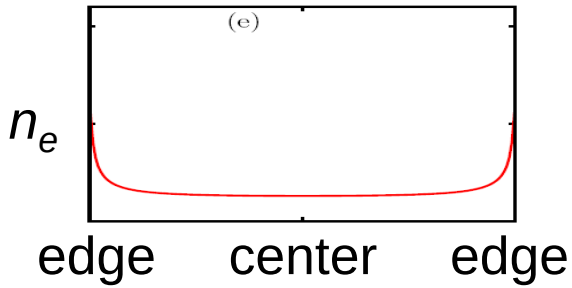
  H. J. Choi, M. L. Cohen, S. G. Louie, *PRB 76, 155420 (2007)*

Effect of Doping on GNRs

Effect of Doping on GNRs

- Back gate controls the doping





Silvestrov *et al* (98)

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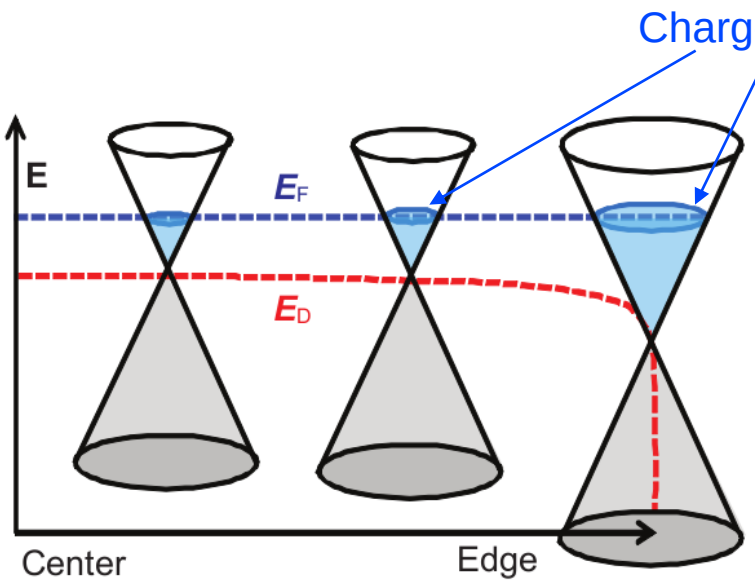
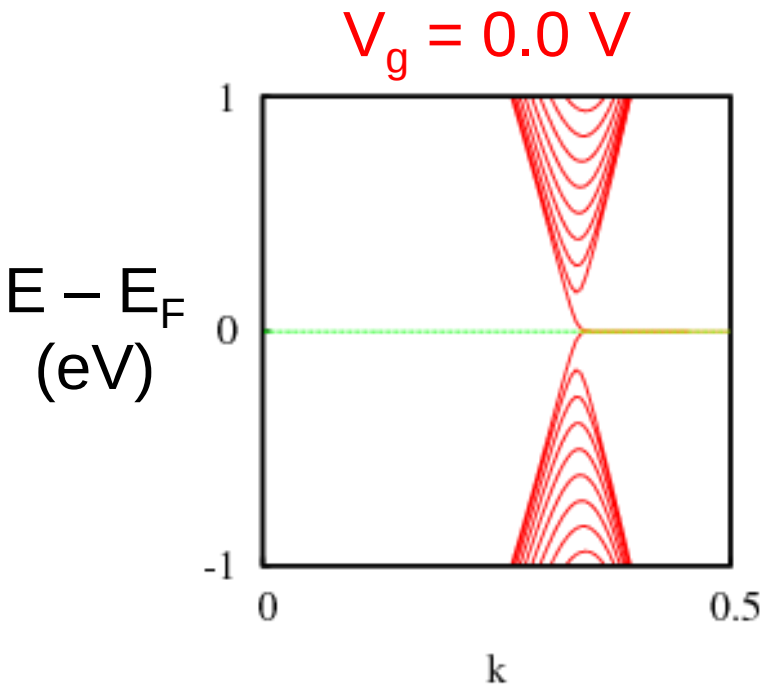


$$E_D \propto \sqrt{n_e}$$

Local E_D can be defined.

Effect of Doping on GNRs

- Doped zigzag-GNR
  - Simulate $E_D(x)$ through on-site energy of tight-binding Hamiltonian



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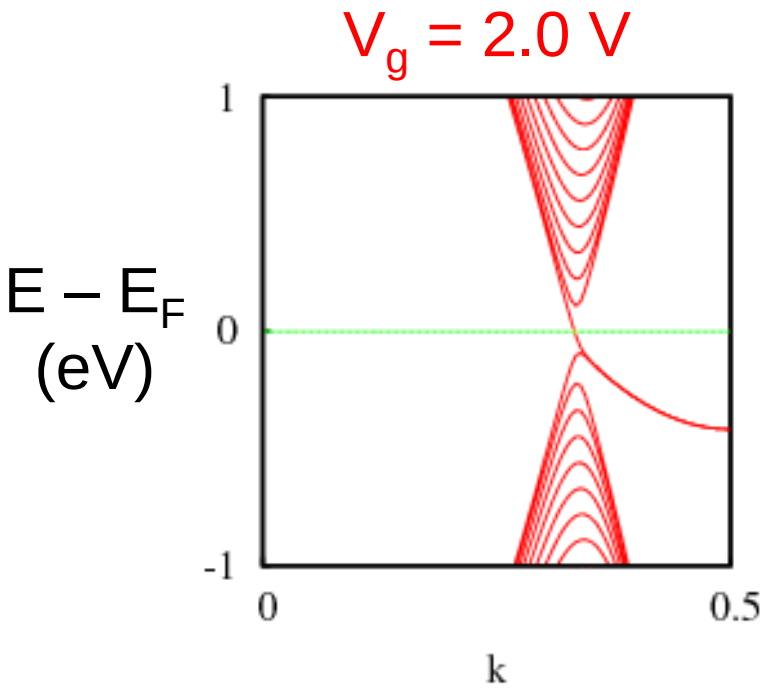

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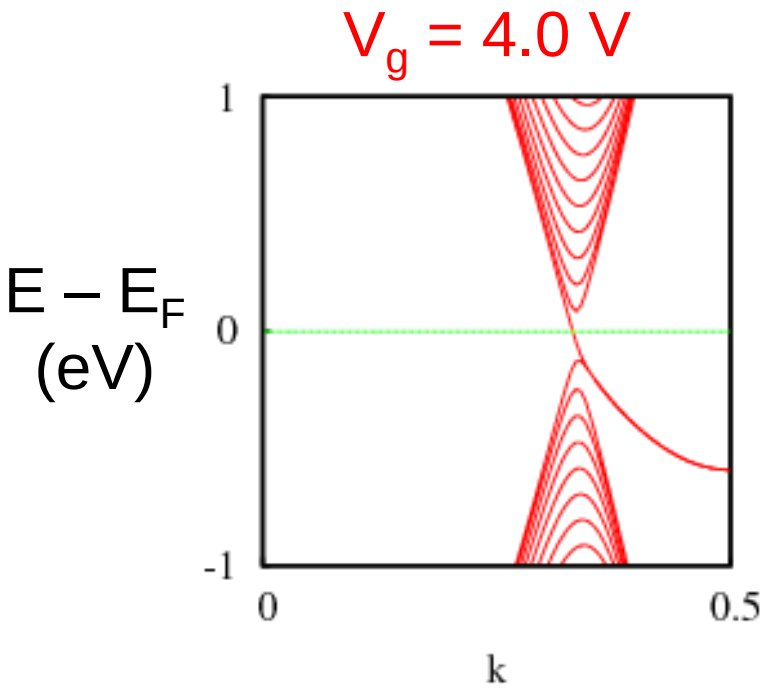

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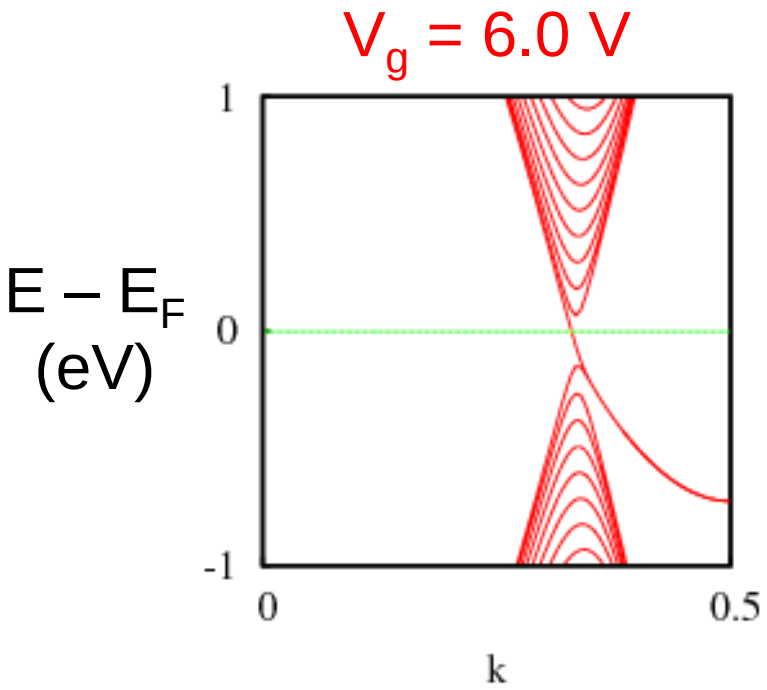

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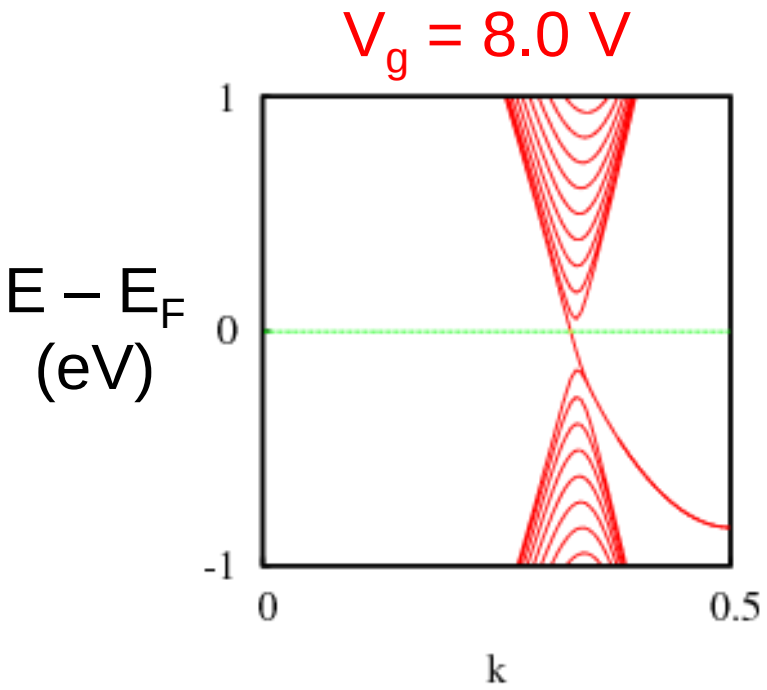

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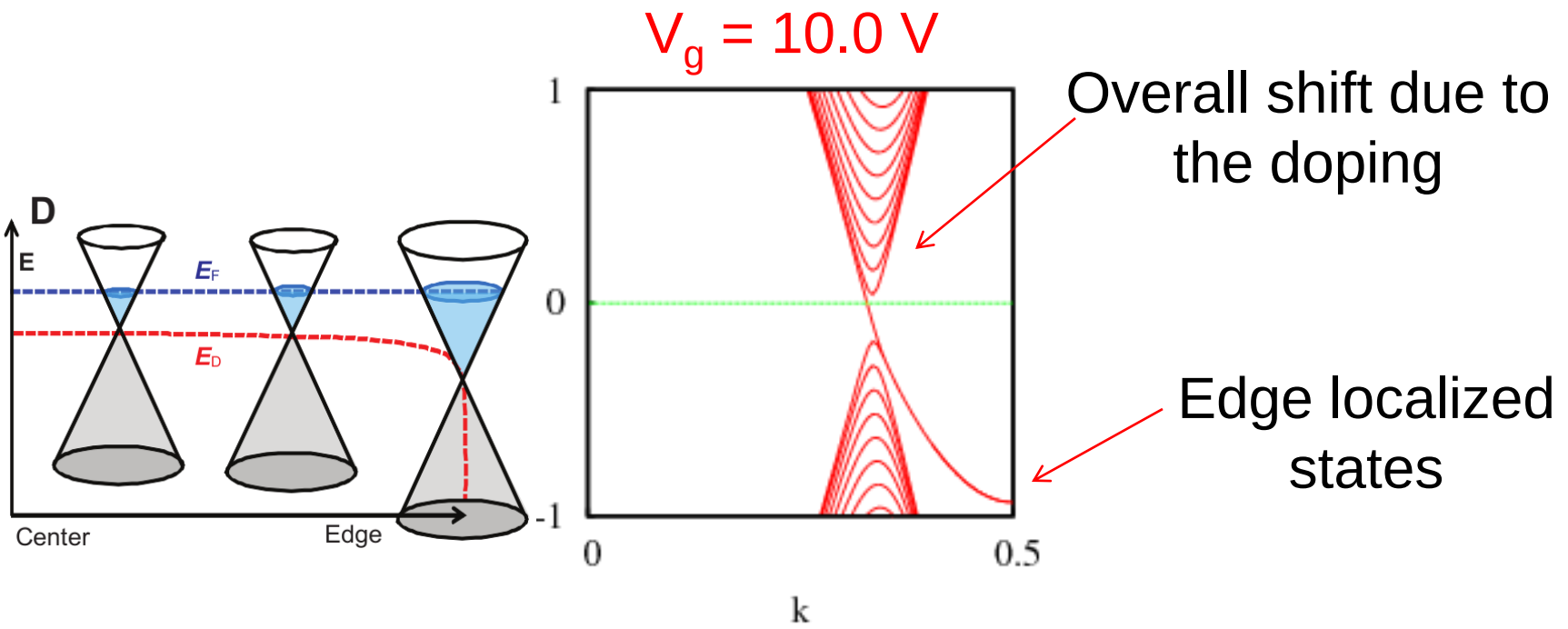

Effect of Tip Potential on doped GNRs

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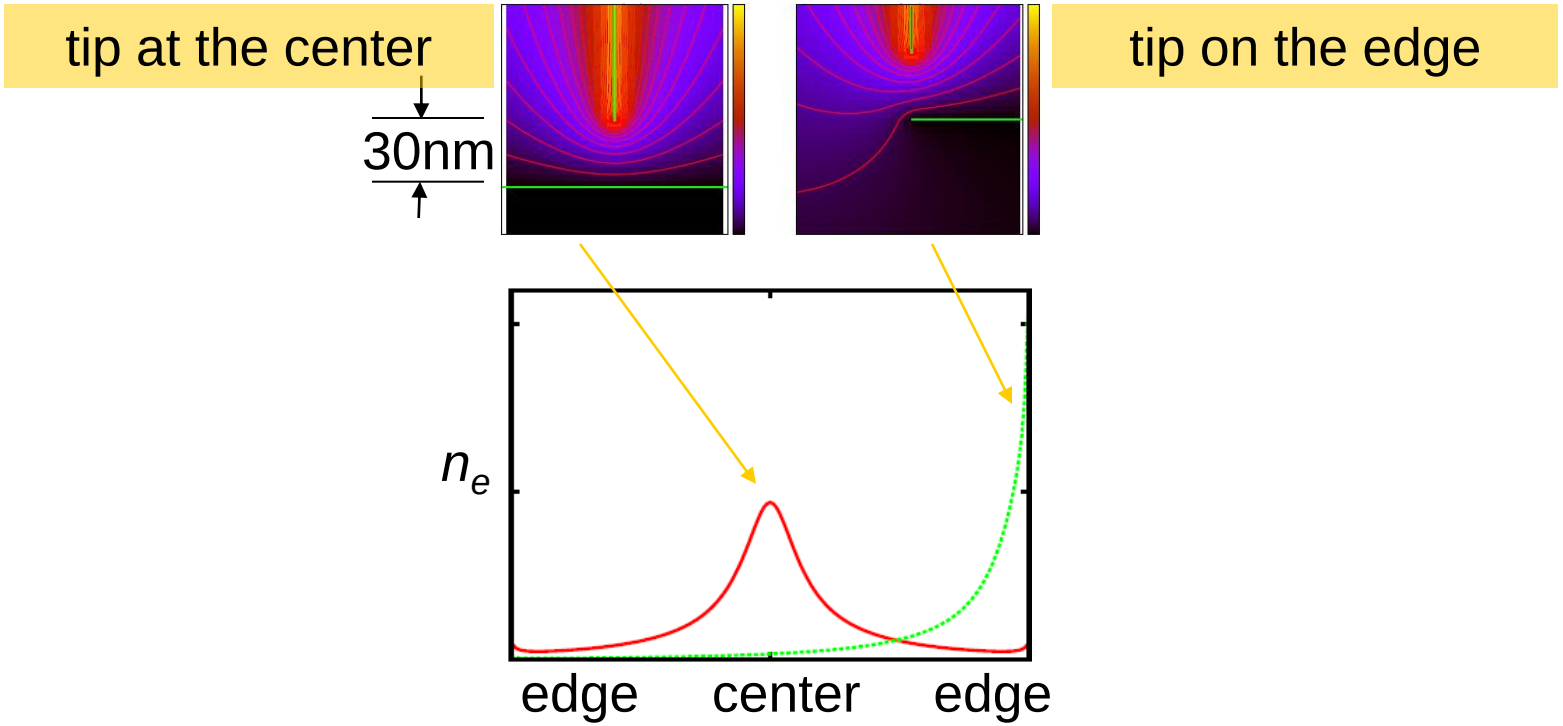
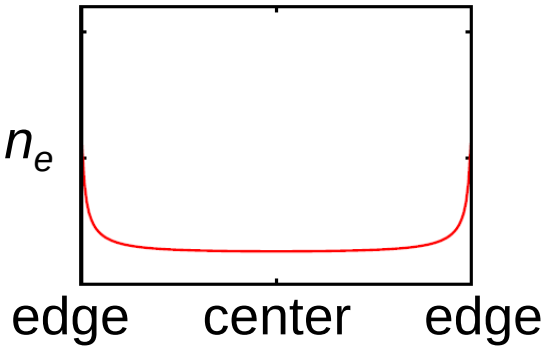
Effect of the Potential Tip on GNRs

- Induced charge density due to the potential tip



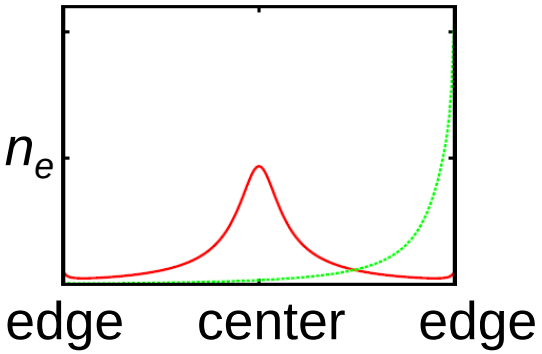
- Back gate (doping)



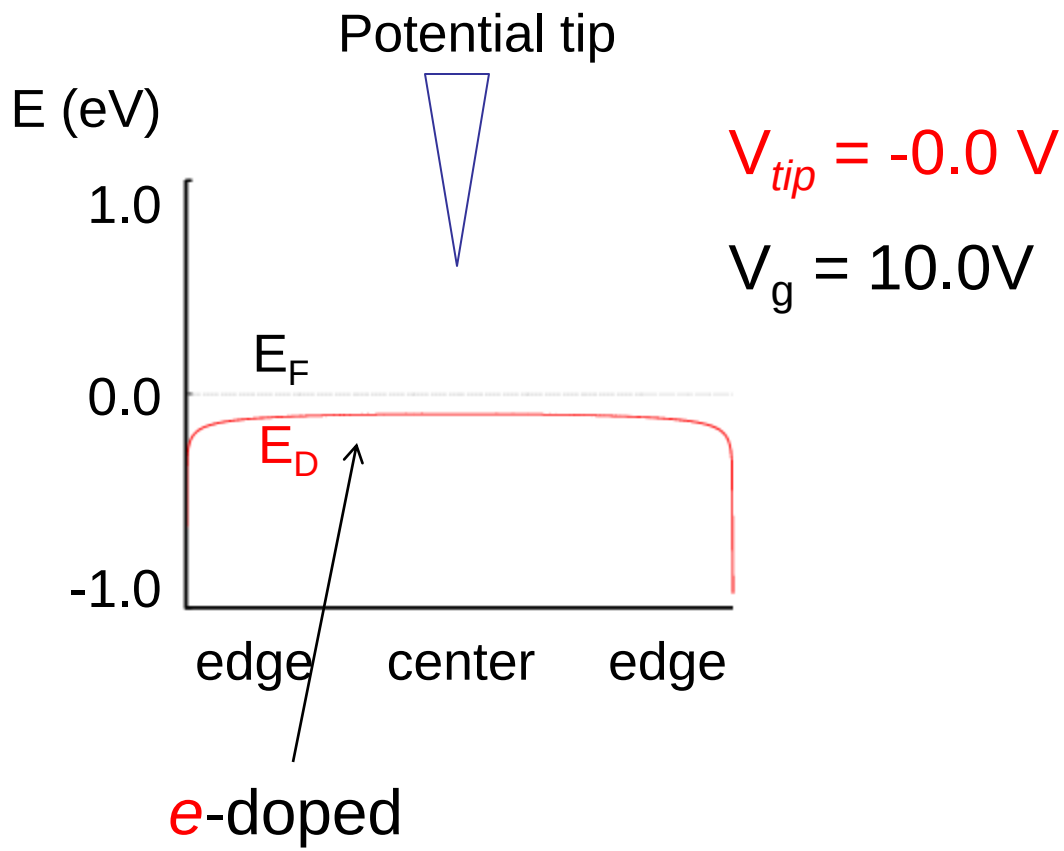
$$n_e = n_{e,g} + n_{e,tip}$$

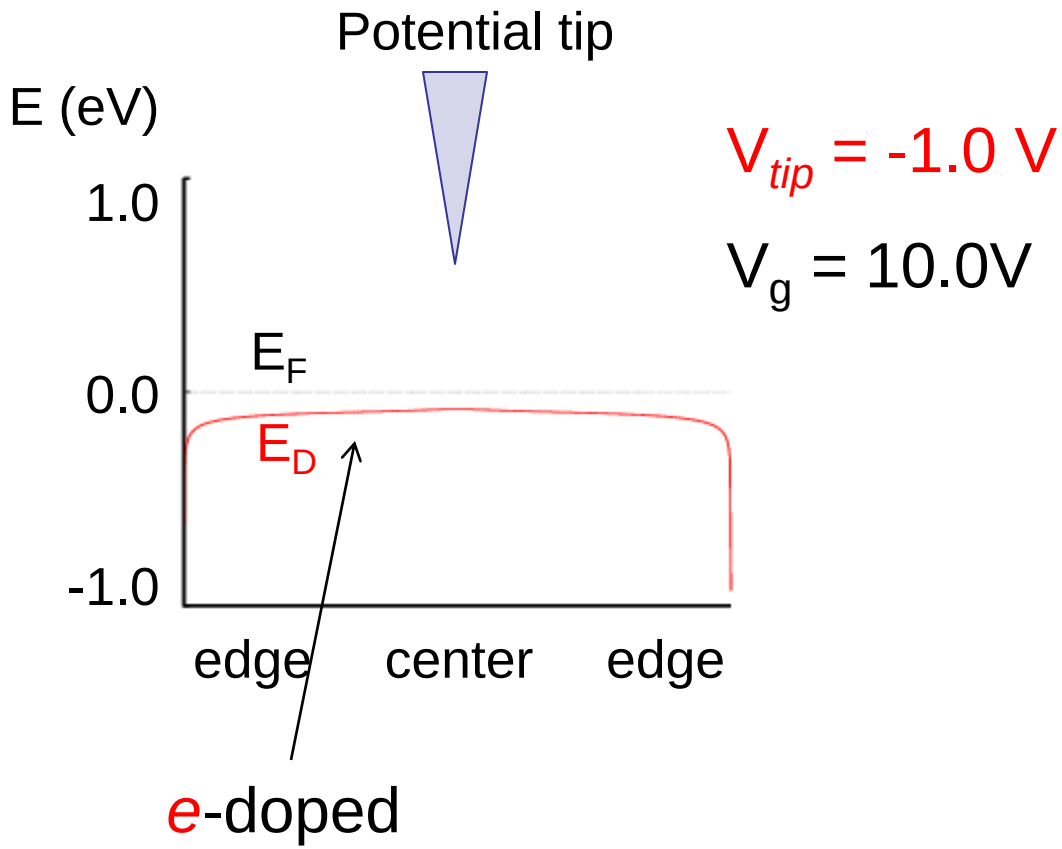
$$E_D \propto \sqrt{n_e}$$

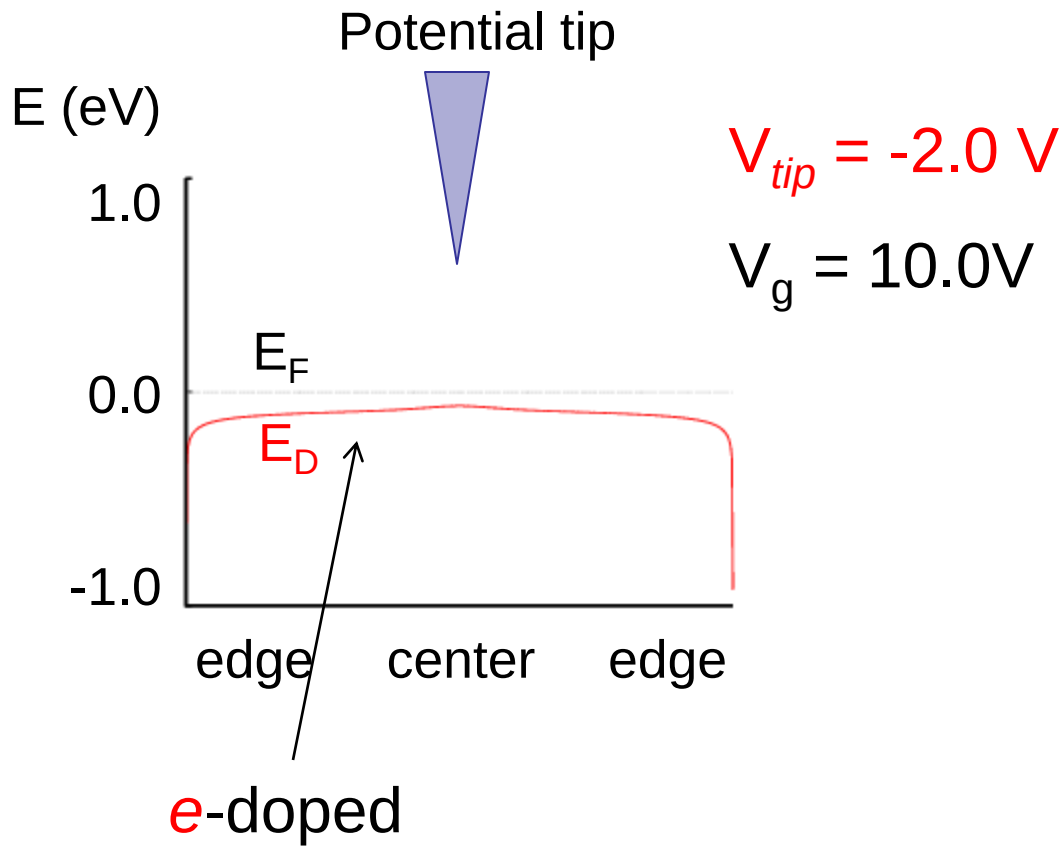
- Tip gate

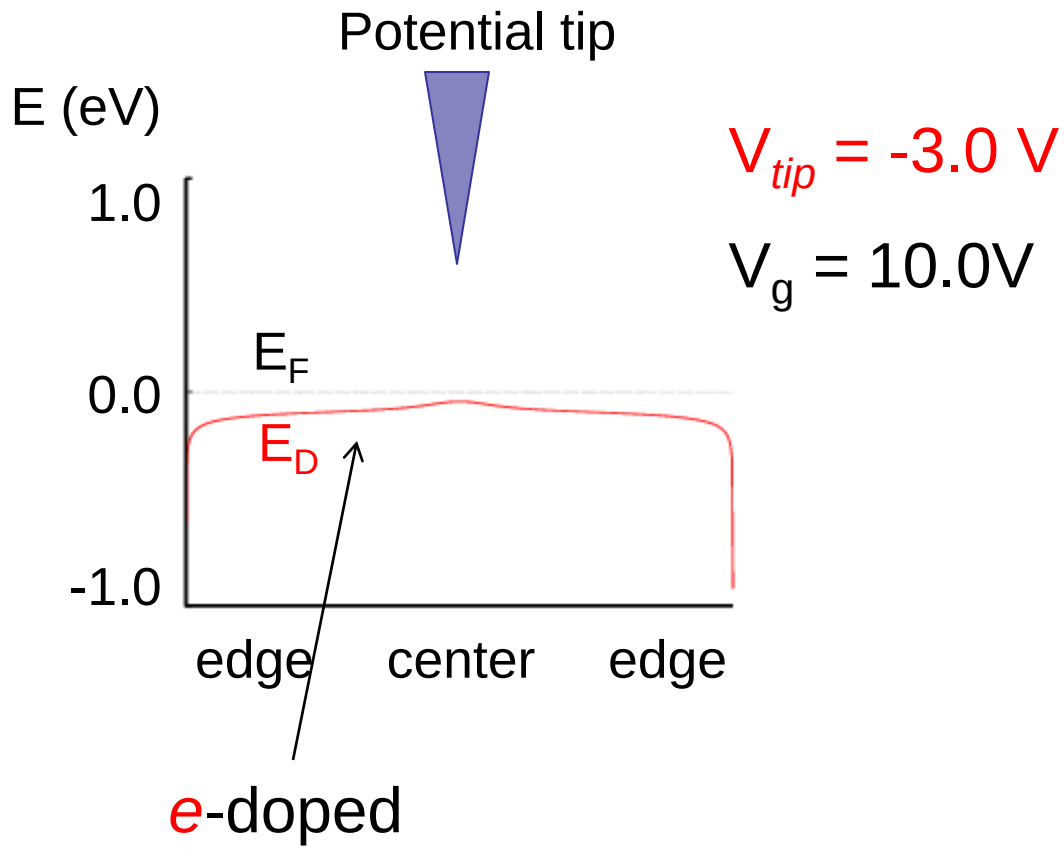


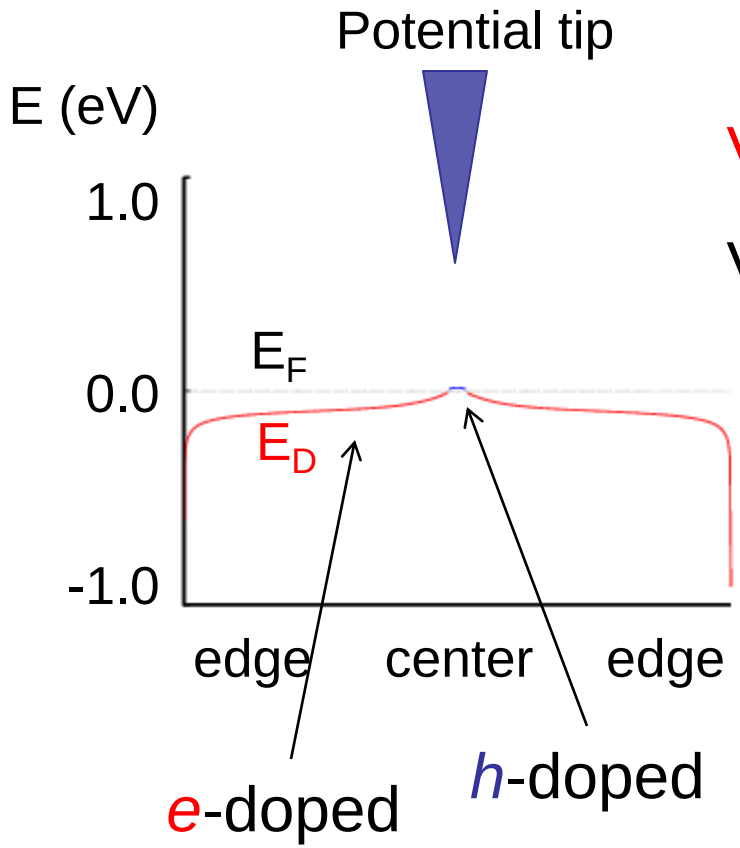
Tip gate voltage is assumed to be homogeneous along the conduction direction


Potential tip
E (eV)
1.0
0.0
-1.0
E_F
E_D
edge
center
edge
e-doped
V_{tip} = -0.0 V
V_g = 10.0V


Potential tip
E (eV)
1.0
0.0
-1.0
E_F
E_D
edge
center
edge
e-doped
V_{tip} = -1.0 V
V_g = 10.0V

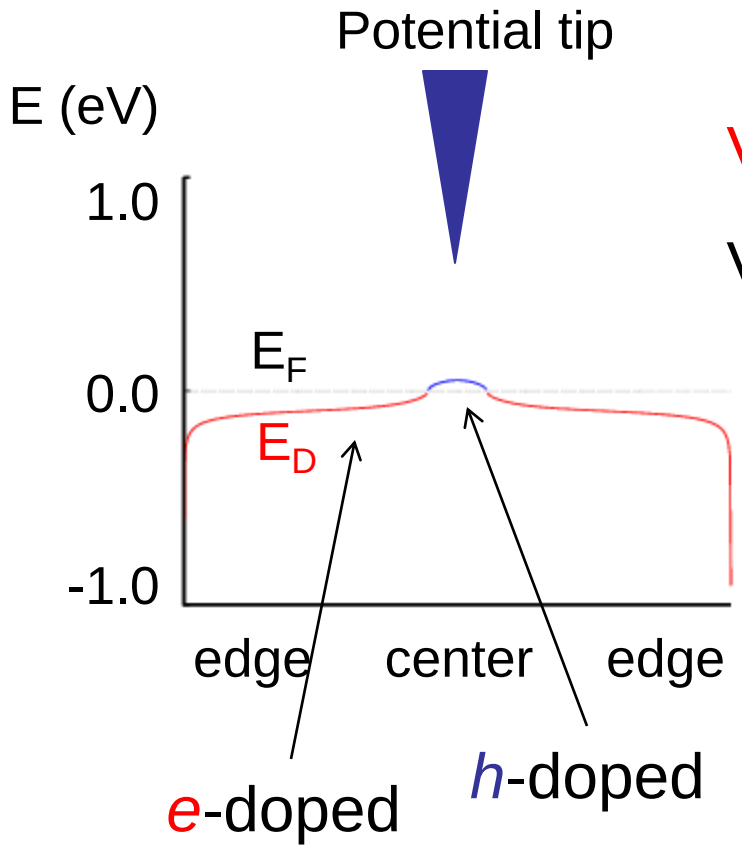

Potential tip
E (eV)
1.0
0.0
-1.0
E_F
E_D
edge
center
edge
e-doped
V_{tip} = -2.0 V
V_g = 10.0V


Potential tip
E (eV)
1.0
0.0
-1.0
E_F
E_D
edge
center
edge
V_{tip} = -3.0 V
V_g = 10.0V
e-doped



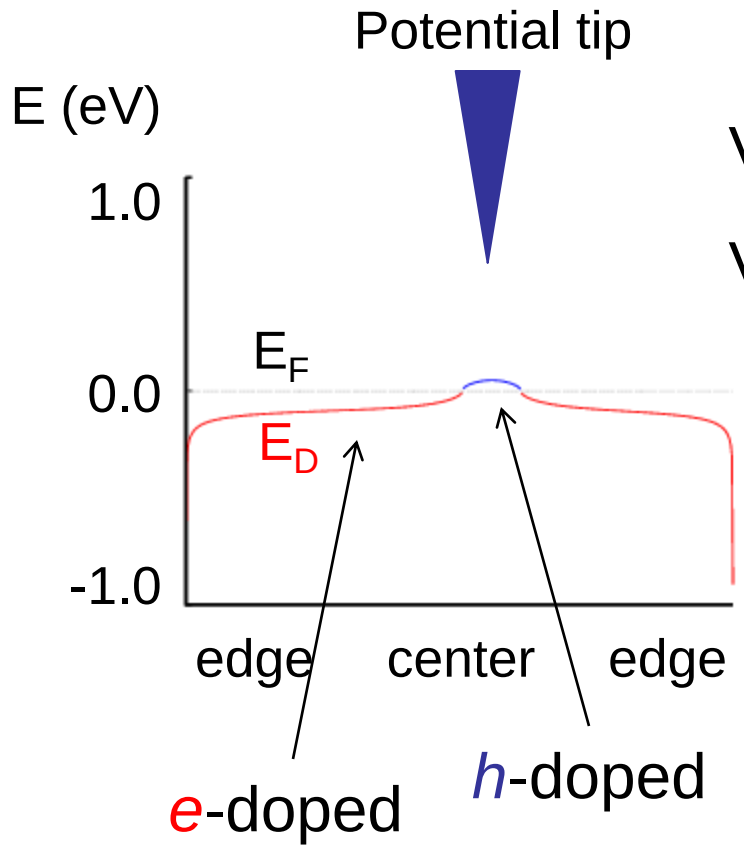
V_{tip} = -4.0 V

V_g = 10.0V



V_{tip} = -5.0 V

V_g = 10.0V



V_{tip} = -5.0 V

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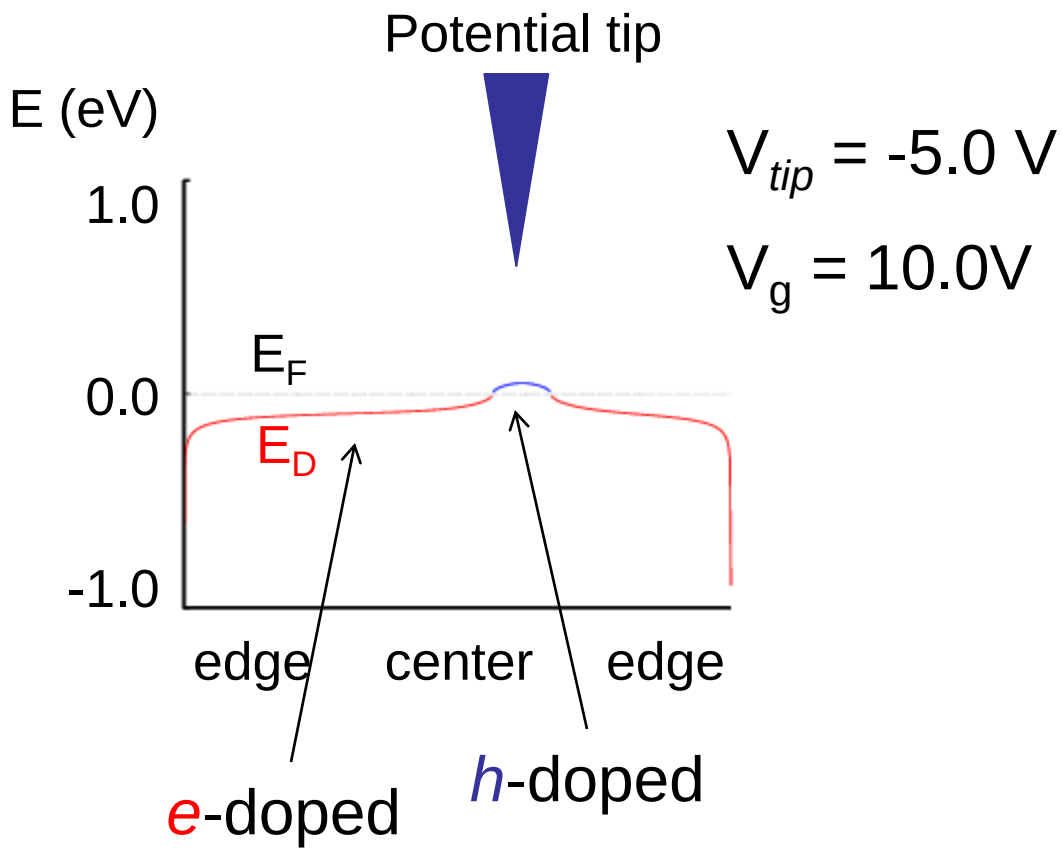
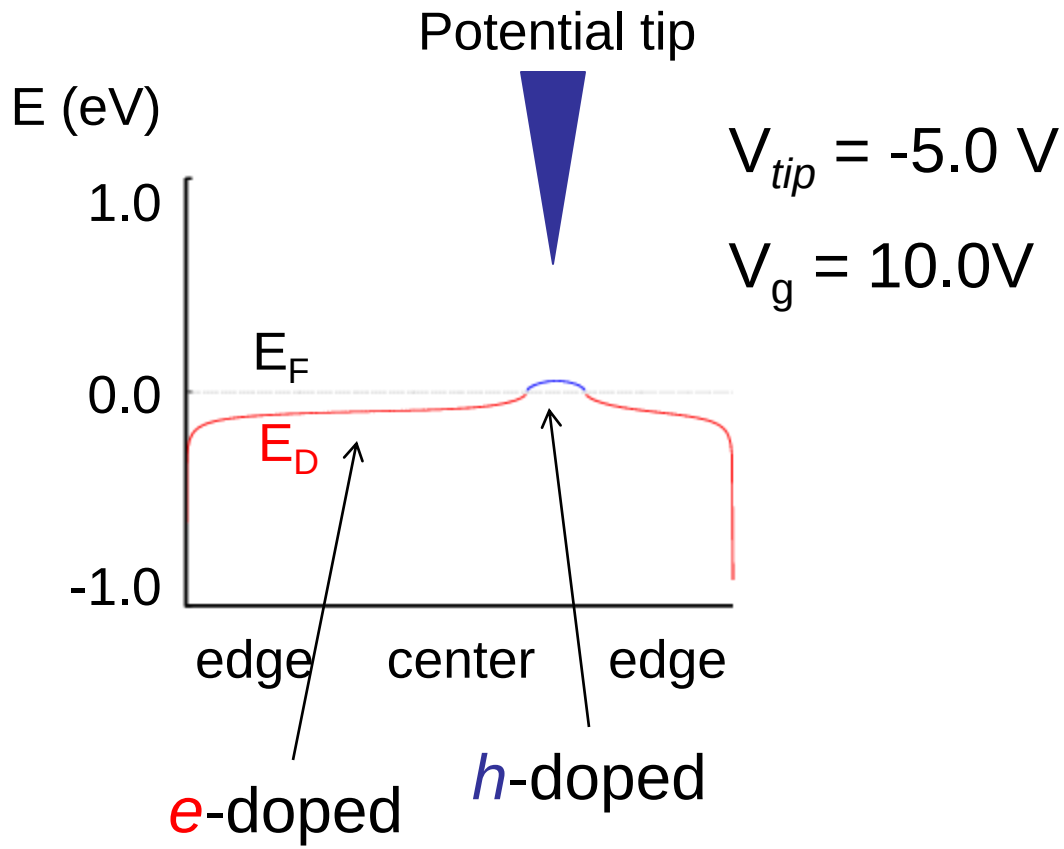

Potential tip
E (eV)
1.0
0.0
-1.0
E_F
E_D
edge
center
edge
e-doped
h-doped
V_{tip} = -5.0 V
V_g = 10.0V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1.0
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E_F
E_D
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center
edge
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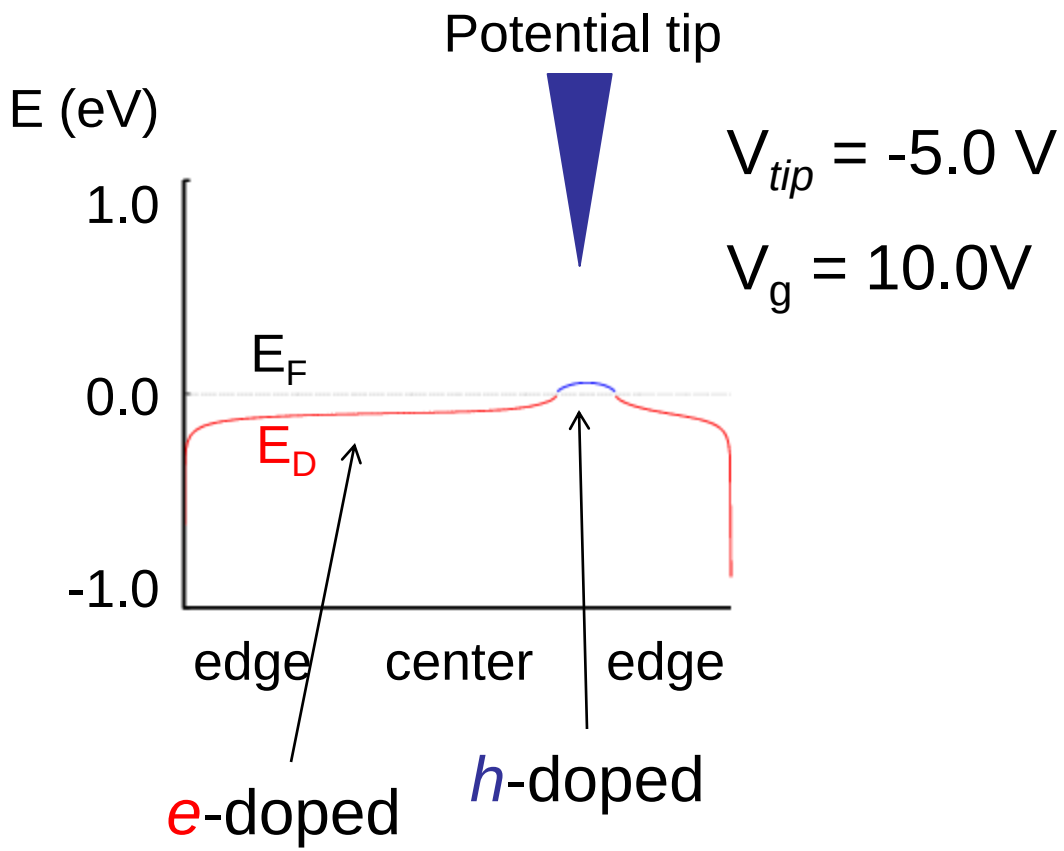
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1.0
0.0
-1.0
E_F
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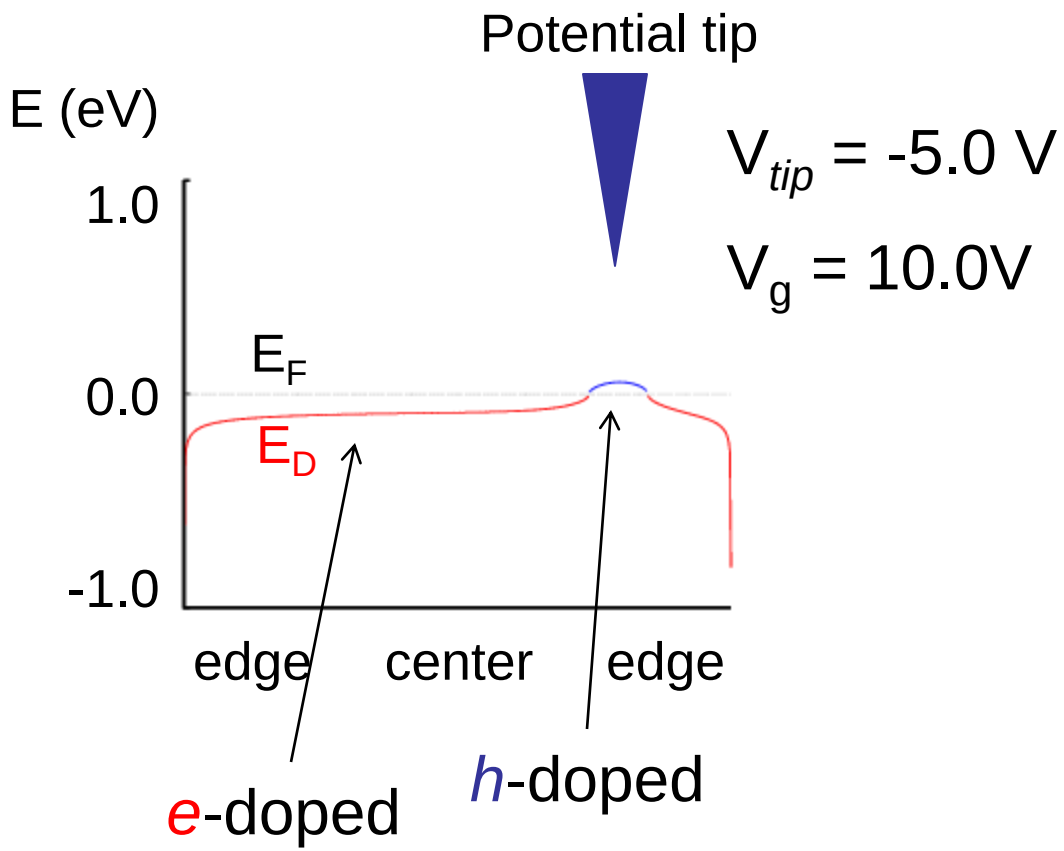
e-doped
h-doped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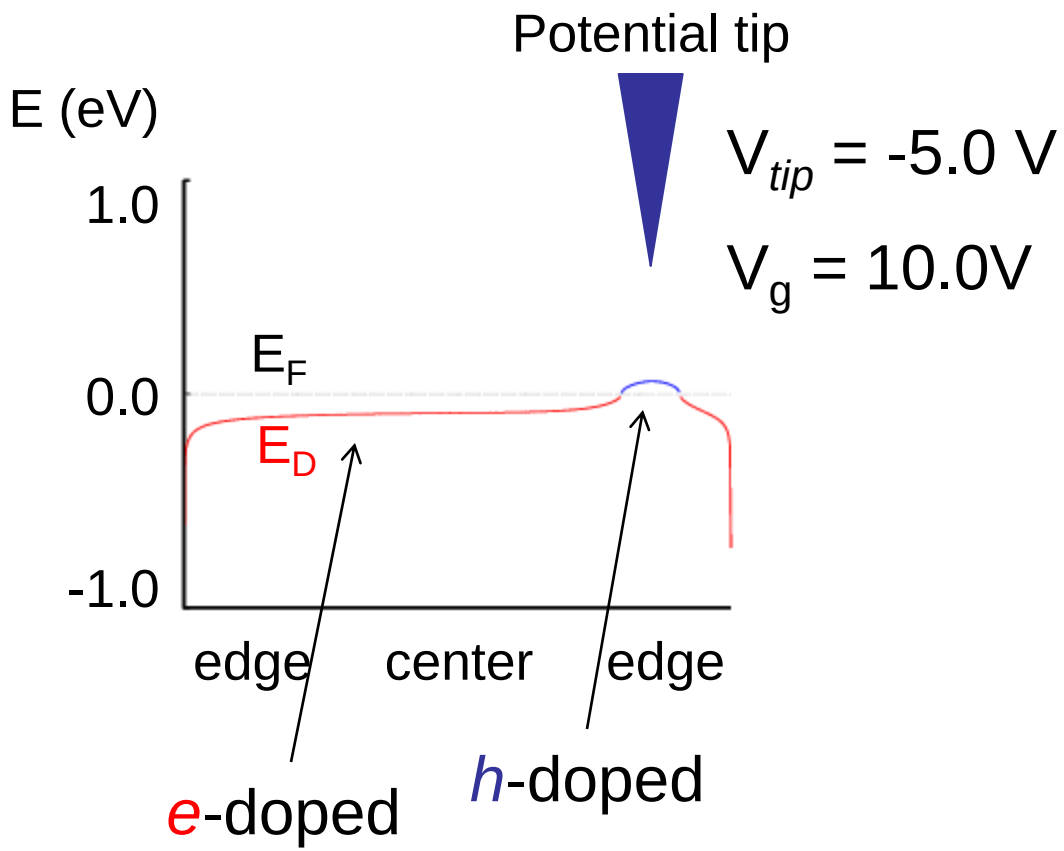
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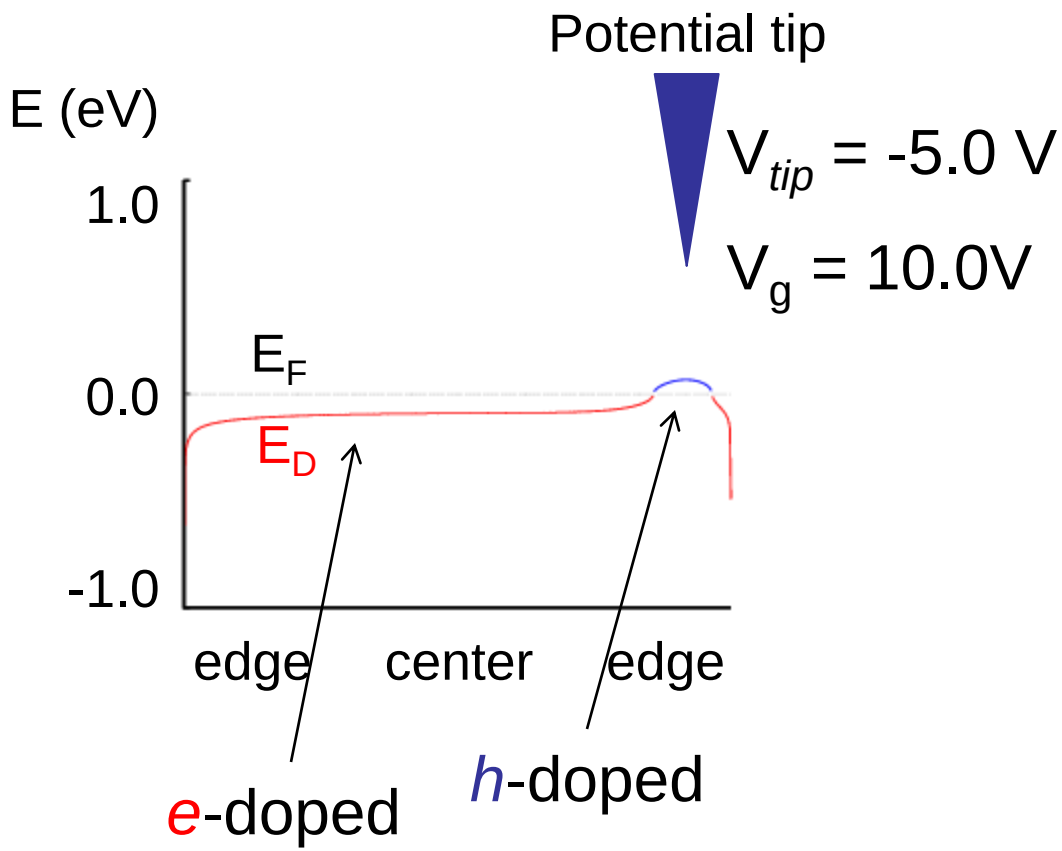
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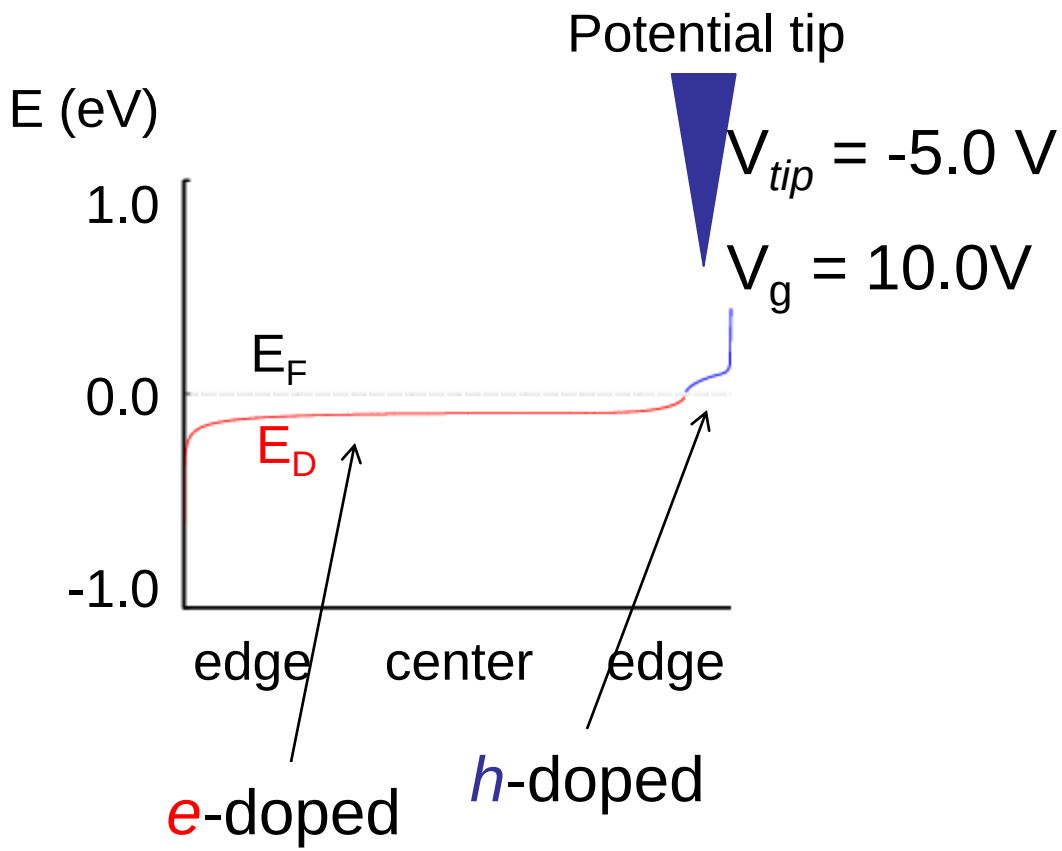
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0.0
-1.0
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E_D
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center
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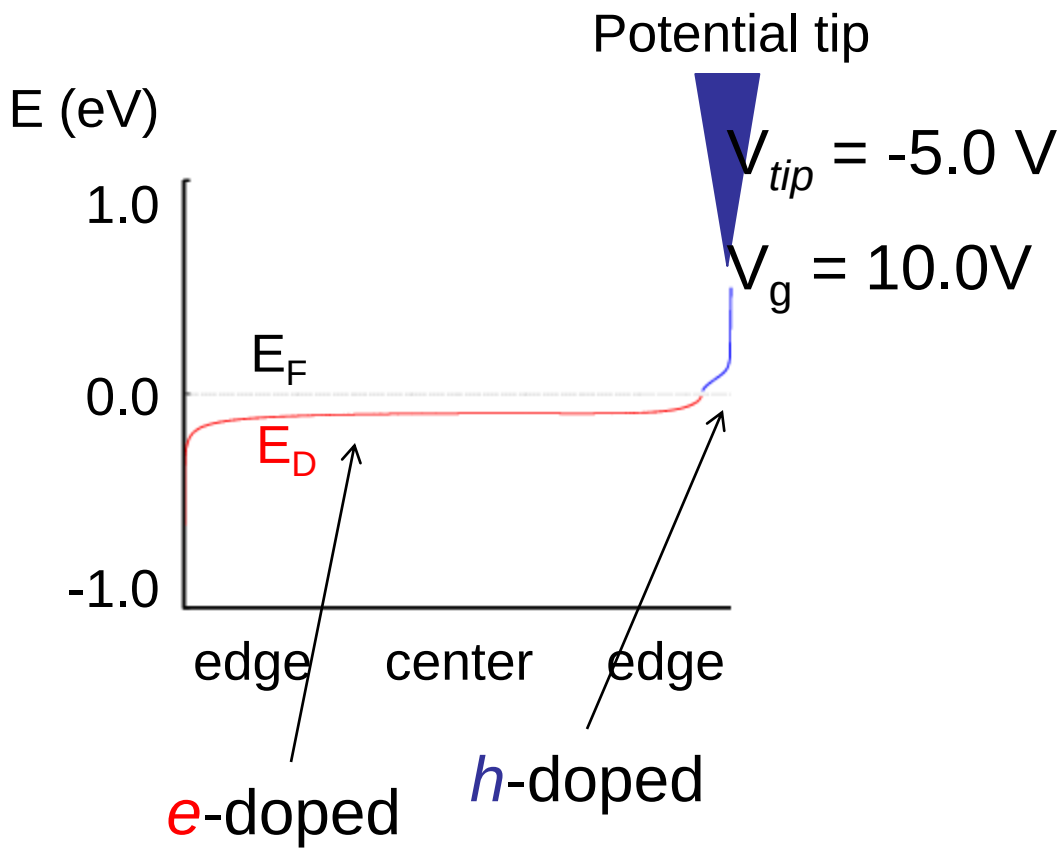
h-doped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E_D
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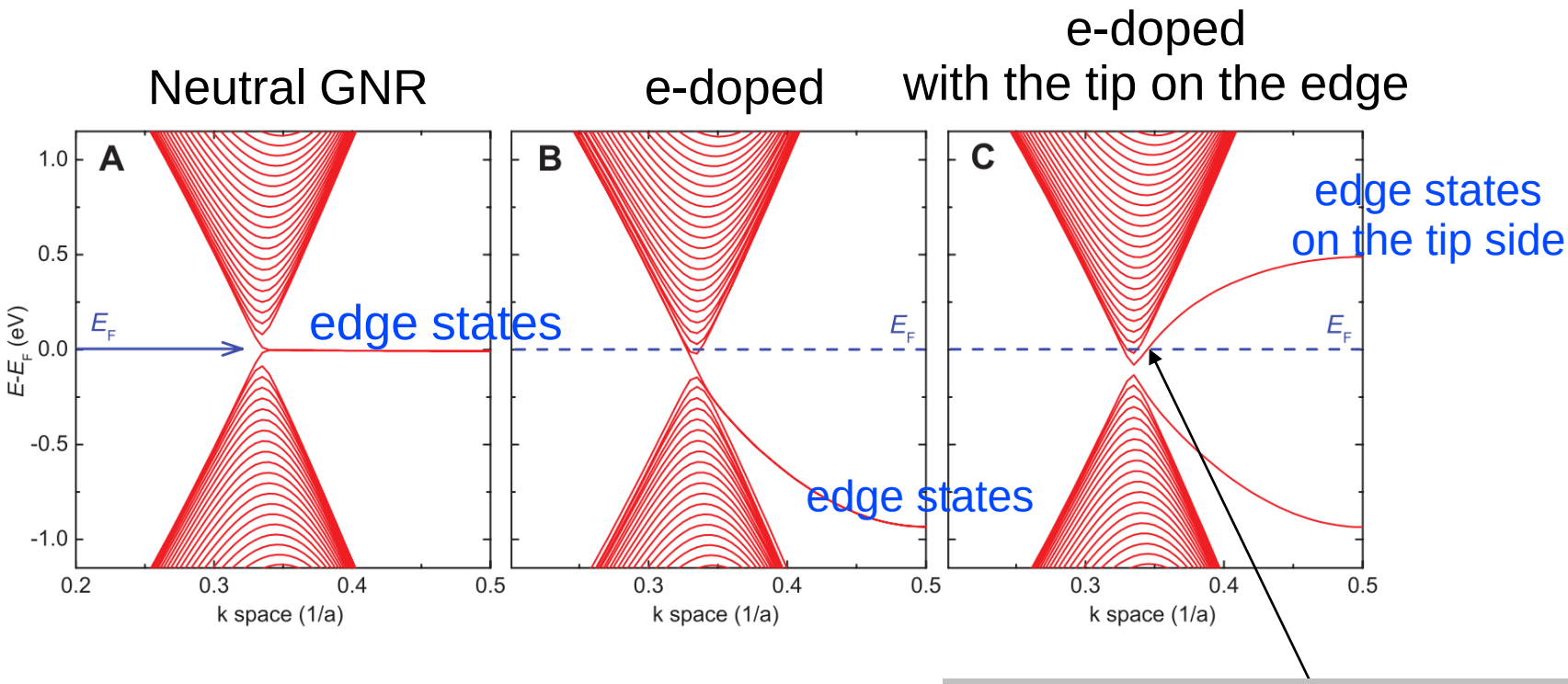

- Edge conductance enhancement occurs on a ***doped GNR*** only when the ***tip potential is against the overall doping***.

Additional conduction channel

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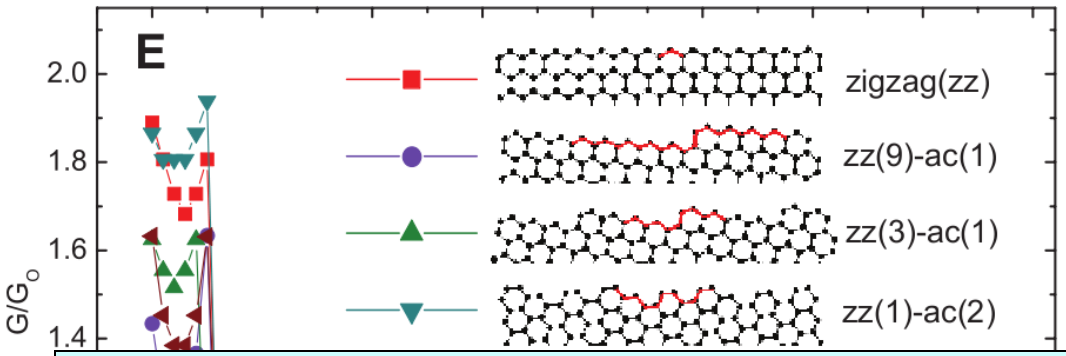
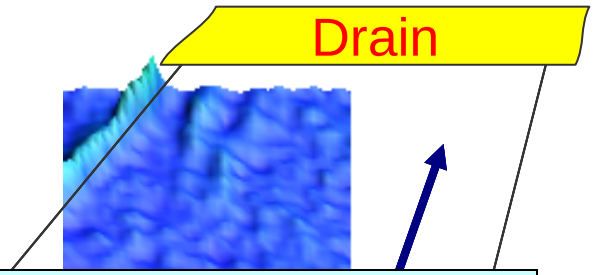
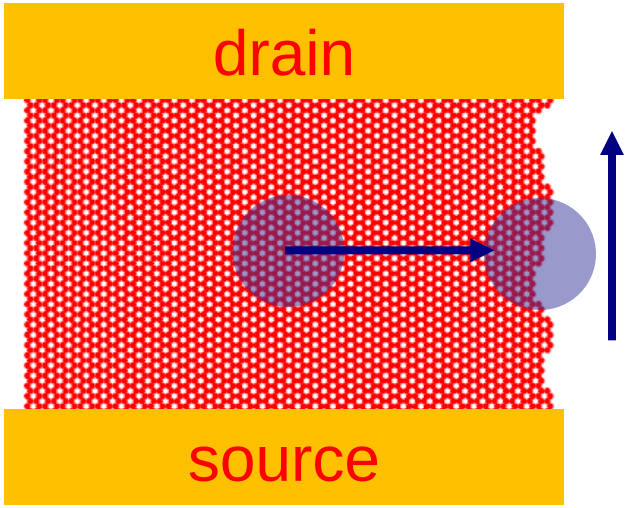
Chiral Edge Structures

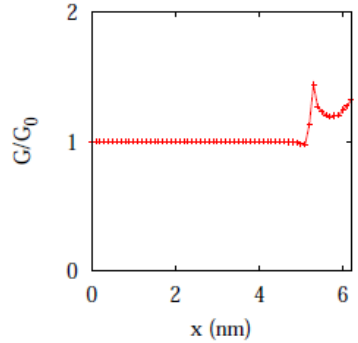




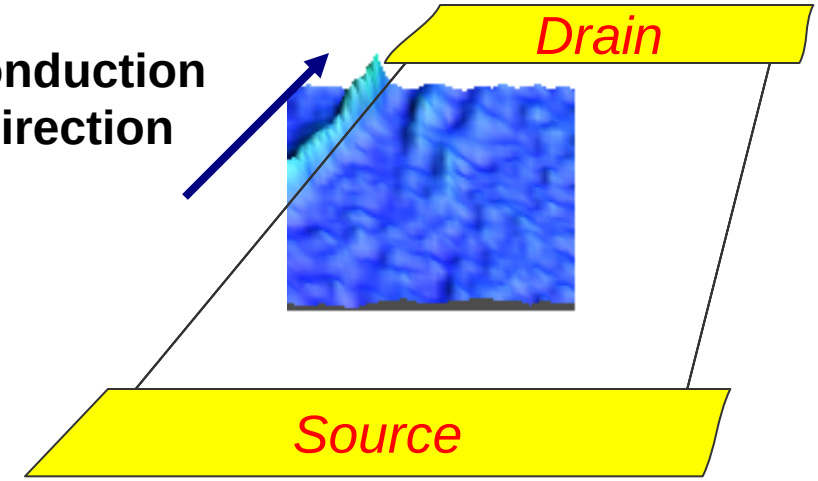
- Localized edge states persist unless the GNR edge is a perfect armchair even though its degree of degeneracy decreases.
- As long as the edge states exist, the amount of conductance enhancement is not affected since it is a “single-channel” effect.

Random Edge Structures with Localized Tip





Conduction direction



Edge conductance enhancement is robust against the detailed edge structure!!

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Conclusion

- Scanning Gate Microscopy on graphene nanoribbons have shown substantial conductance enhancement when the tip is positioned near the edge of the ribbon.
- Edge conductance enhancement that shows edge conducting channel only when the GNR is doped and the SGM tip voltage is against the GNR doping.
- This phenomena is attributed to the ultrasharp edge of graphene nanoribbon that enables high charge accumulation on the edge.
- Conductance enhancement has little correlation with the detailed edge structure.

Thank you

for your attention!