Quantum transport in vdW heterostructures of graphene and 2D materials

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June 11, 2015

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Outline

Transfer technique of atomic layers

Quantum Hall pnp junctions

- Novel magnetoresistance oscillations
- Coherent interference in QH edge channels

Graphene/h-BN

Magnetic tunnel junctions

- Magnetoresistance effect

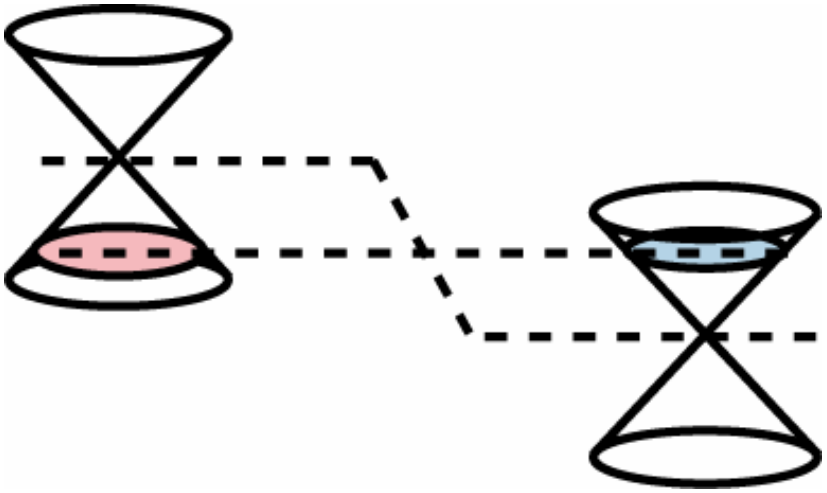
$Fe_{0.25}TaS_2/Fe_{0.25}TaS_2$

Josephson junctions

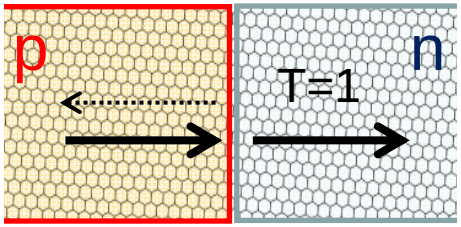
- Supercurrent
- Fraunhofer pattern and Fiske resonance

$NbSe_2/NbSe_2$

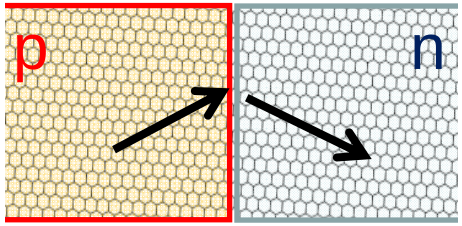
Graphene p-n junctions



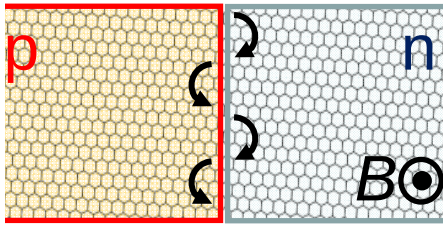
Dirac cone
Gapless
Pseudo spin



Klein Tunneling



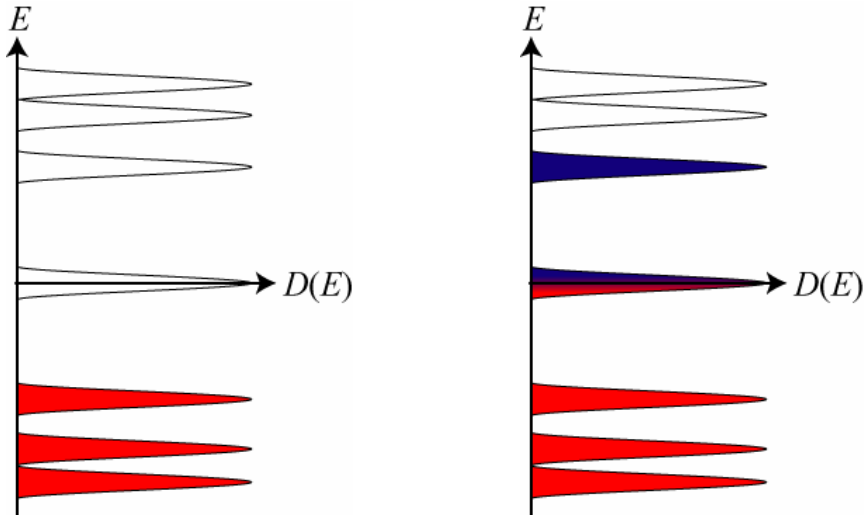
Negative refractive index



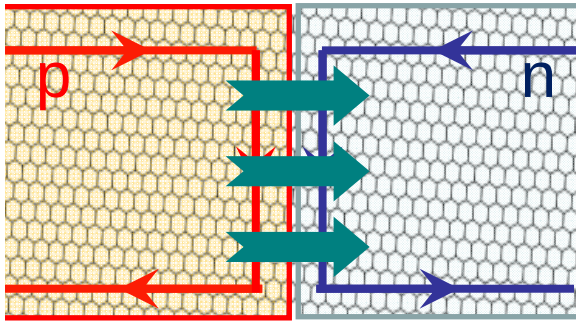
Snake States

Quantum transport of Dirac fermions

Graphene p-n junctions in high *B*



Landau quantization
QHE

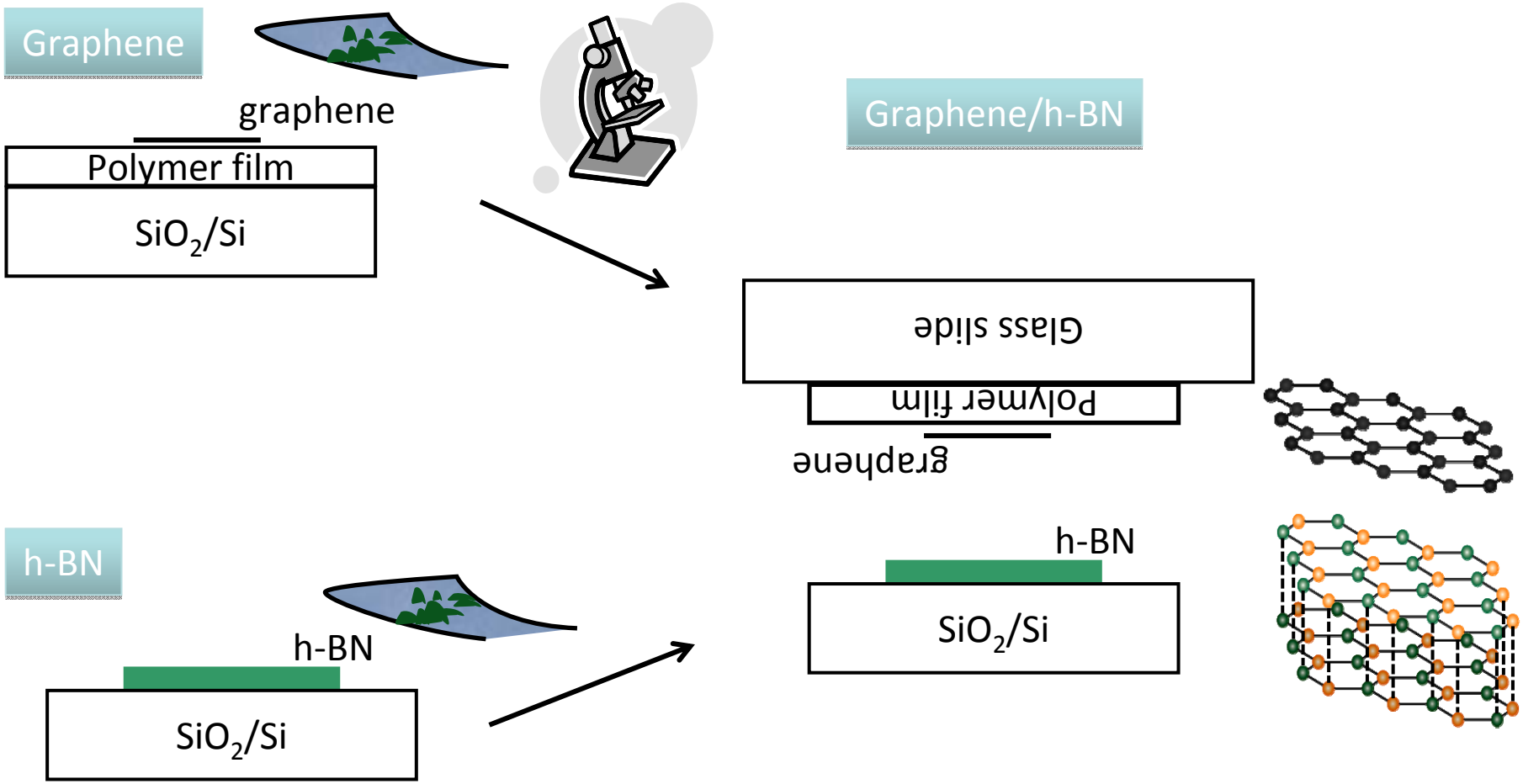


Counter-circulating quantum Hall edge channels

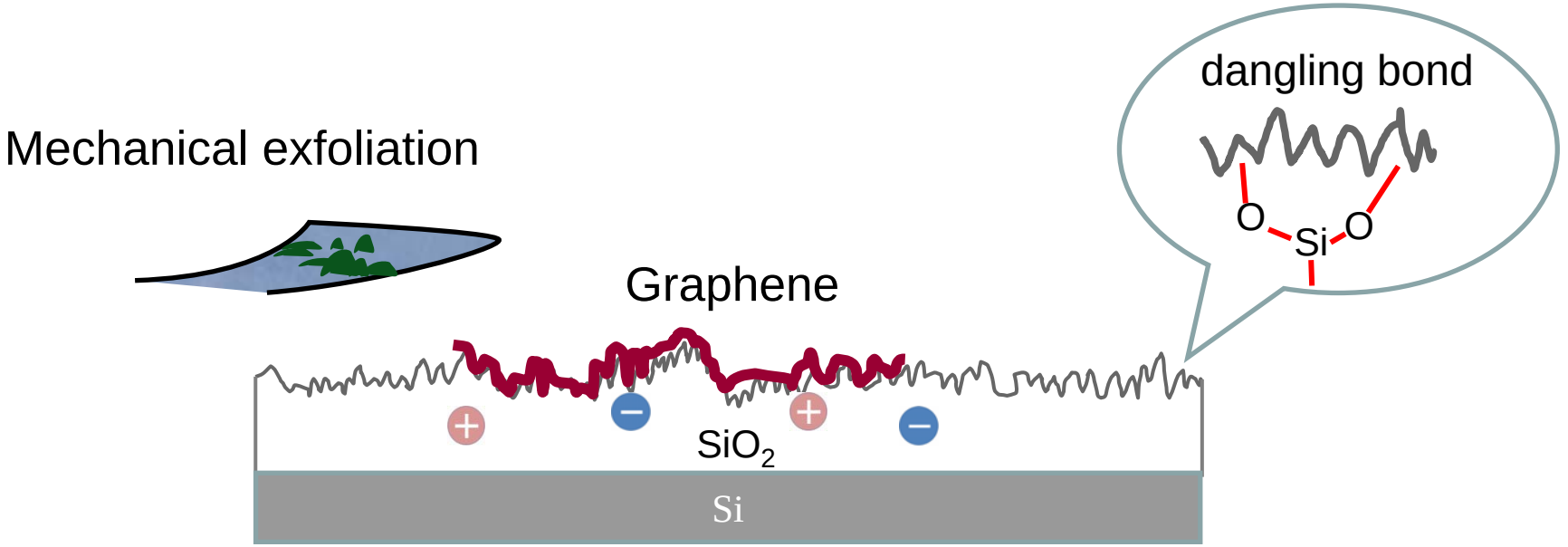
Novel resistance oscillations

Co-propagating quantum Hall edge channels

Transfer of atomic layers



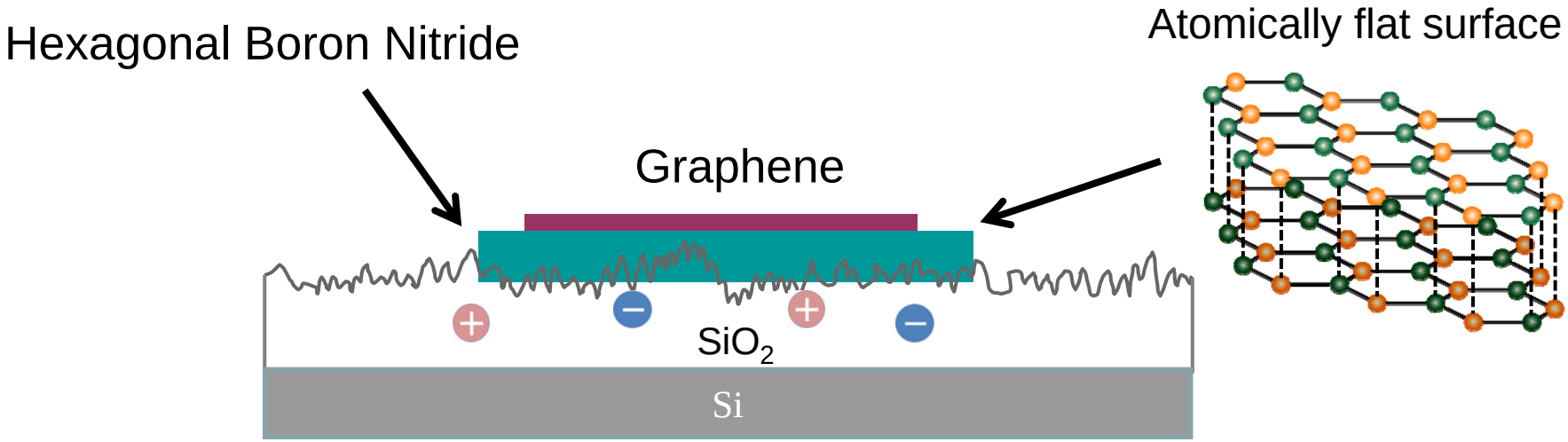
Graphene on SiO_2



Surface roughness
Dangling bonds
Charged impurity
SiO_2 optical phonon (60 meV)

Mobility limited by extrinsic scattering sources

Graphene on SiO_2 v.s. graphene on h-BN

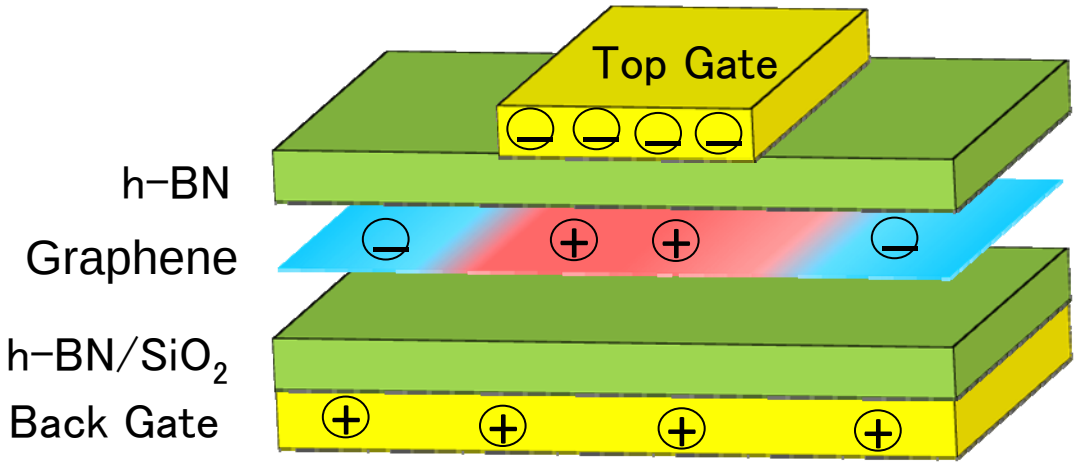


Surface roughness
Dangling bonds
Charged impurity
SiO_2 optical phonon (60 meV)

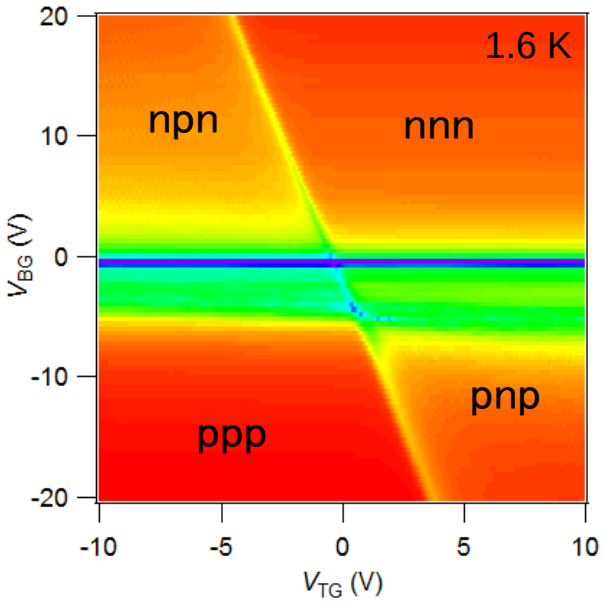
Atomically flat surface
No dangling bonds
Honeycomb lattice
BN optical phonon (100 meV)

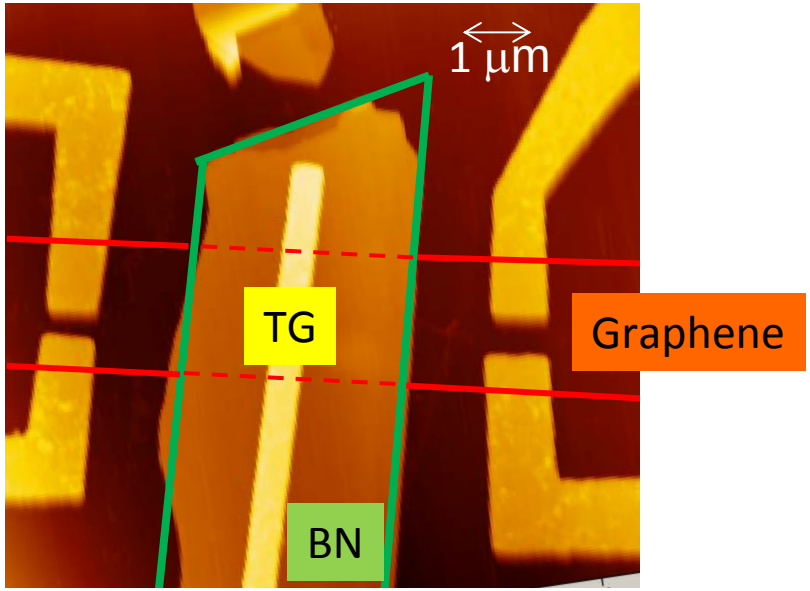
Extrinsic scattering sources suppressed

h-BN / Graphene /h-BN

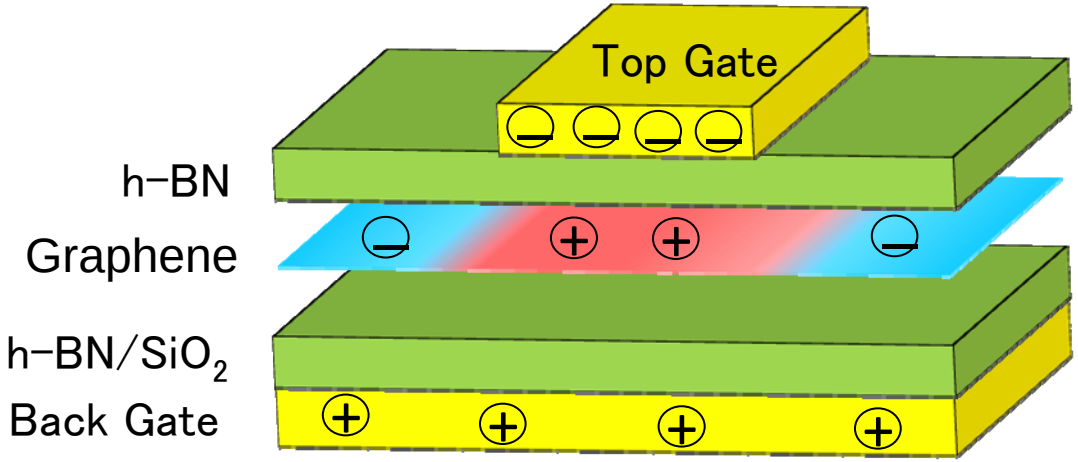


$\mu \sim 10^5$ cm^2/Vs@RT

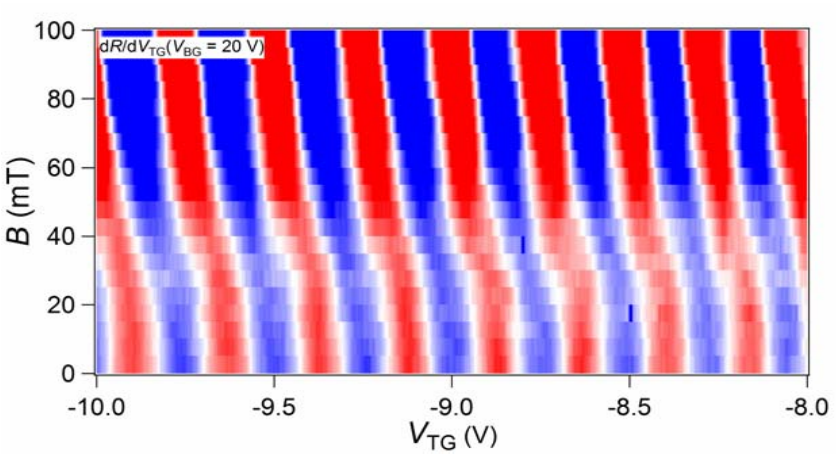


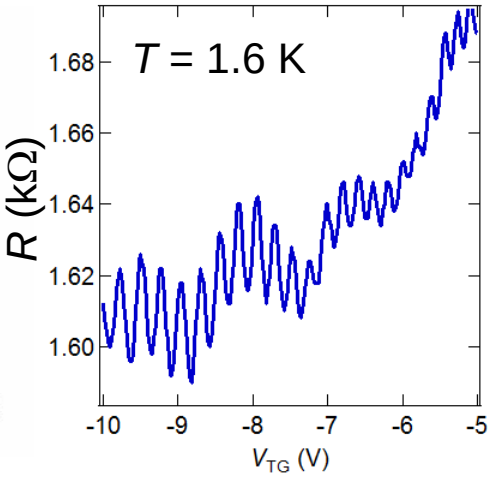


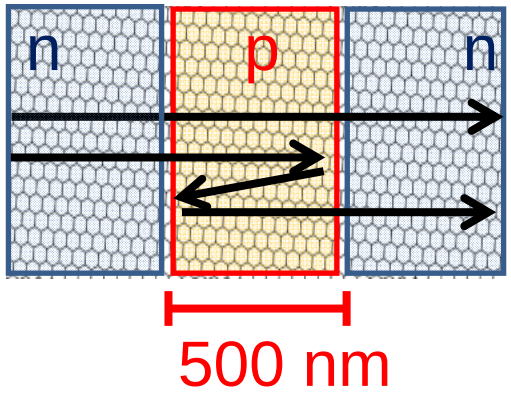
h-BN / Graphene /h-BN



$\mu \sim 10^5$ cm^2/Vs@RT

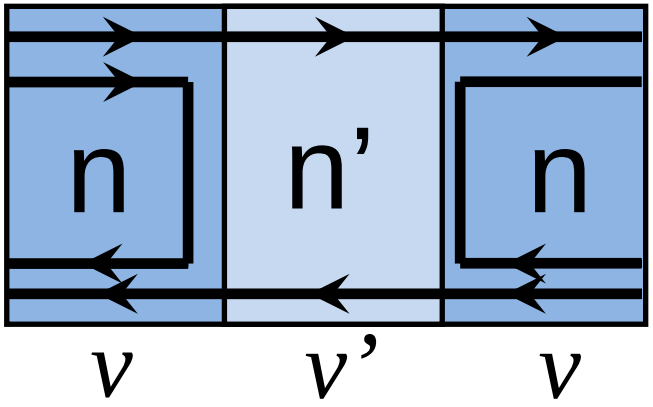




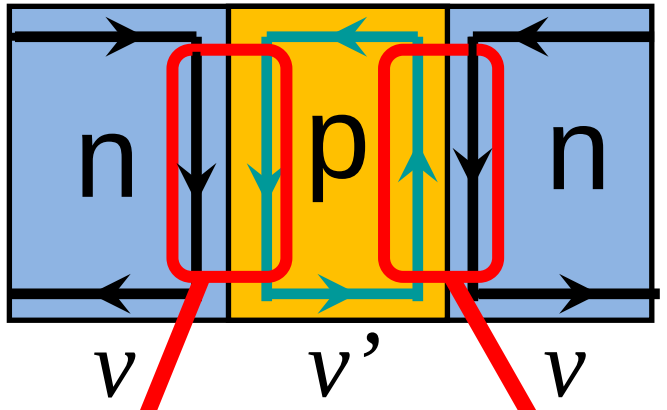


High quality graphene n-p-n junctions (L_ϕ > 500 nm)

n-n’-n / n-p-n quantum Hall junctions

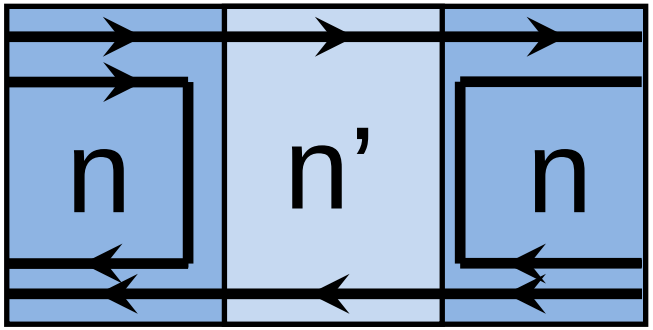


$$R = \frac{h}{e^2}\frac{1}{\nu'}$$

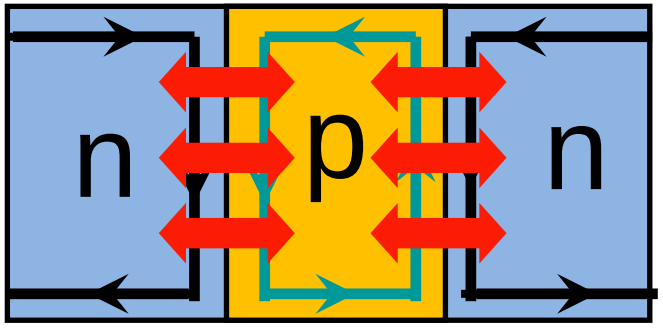


Co-propagating
edge channel

n-n’-n / n-p-n quantum Hall junctions



$$R = \frac{h}{e^2}\frac{1}{\nu'}$$



B

$$R = \frac{h}{e^2}\left(\frac{2}{\nu} + \frac{1}{\nu'}\right) = \frac{h}{e^2}\frac{2\nu' + \nu}{\nu\nu'}$$

for fully-mixed QH edge channels

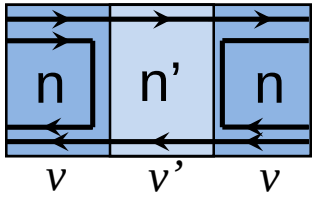
B. Ozyilmaz *et al*., PRL **99**, 166804 (2007).

$$R > \frac{h}{e^2}\frac{2\nu' + \nu}{\nu\nu'}$$

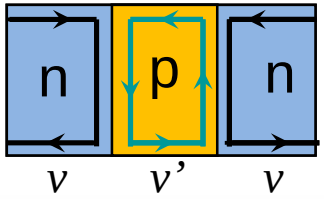
for adiabatic QH edge channels

F. Amet *et al*., PRL**112**, 196601 (2014).

n-p-n quantum Hall junctions

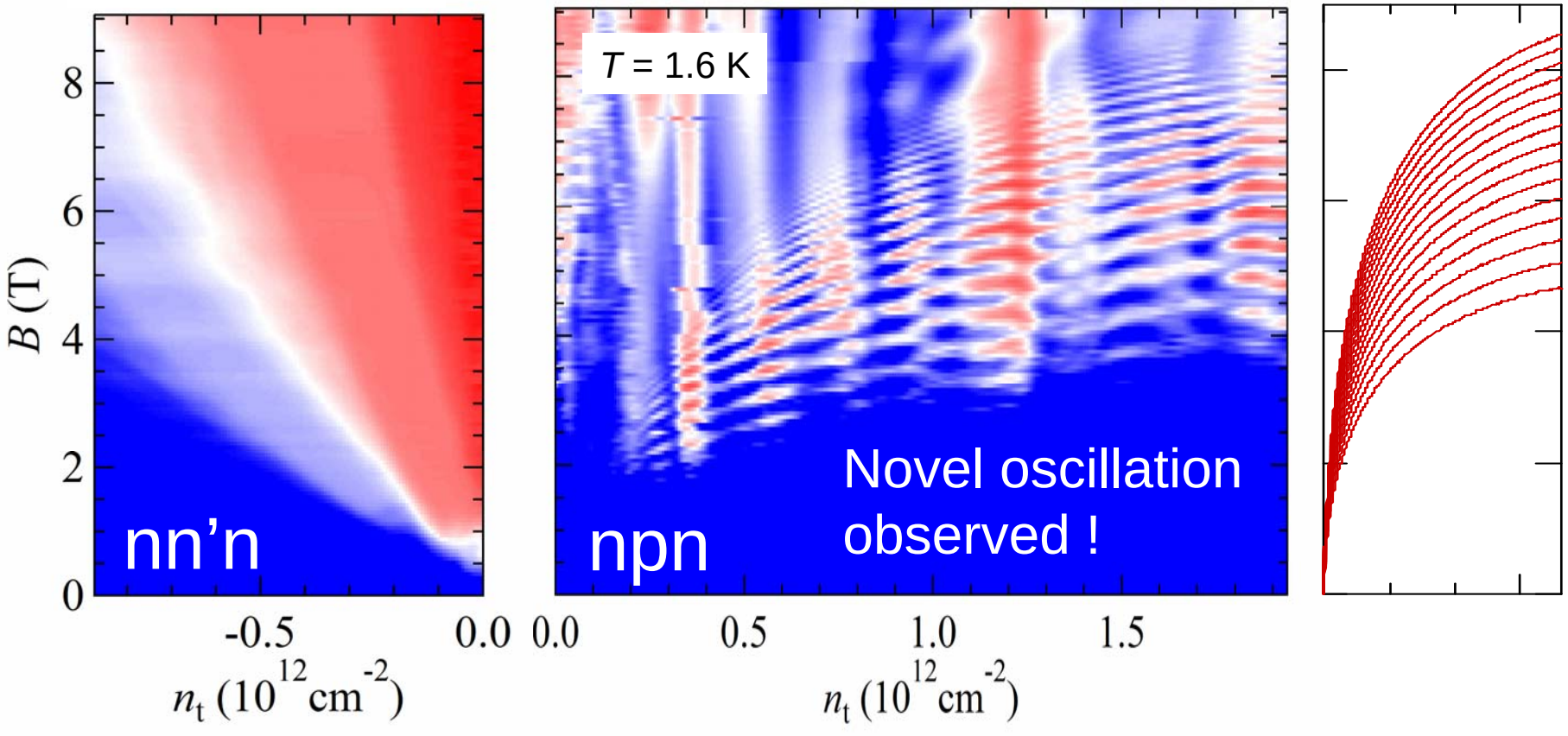


$$R = \frac{h}{e^2}\frac{1}{\nu'}$$

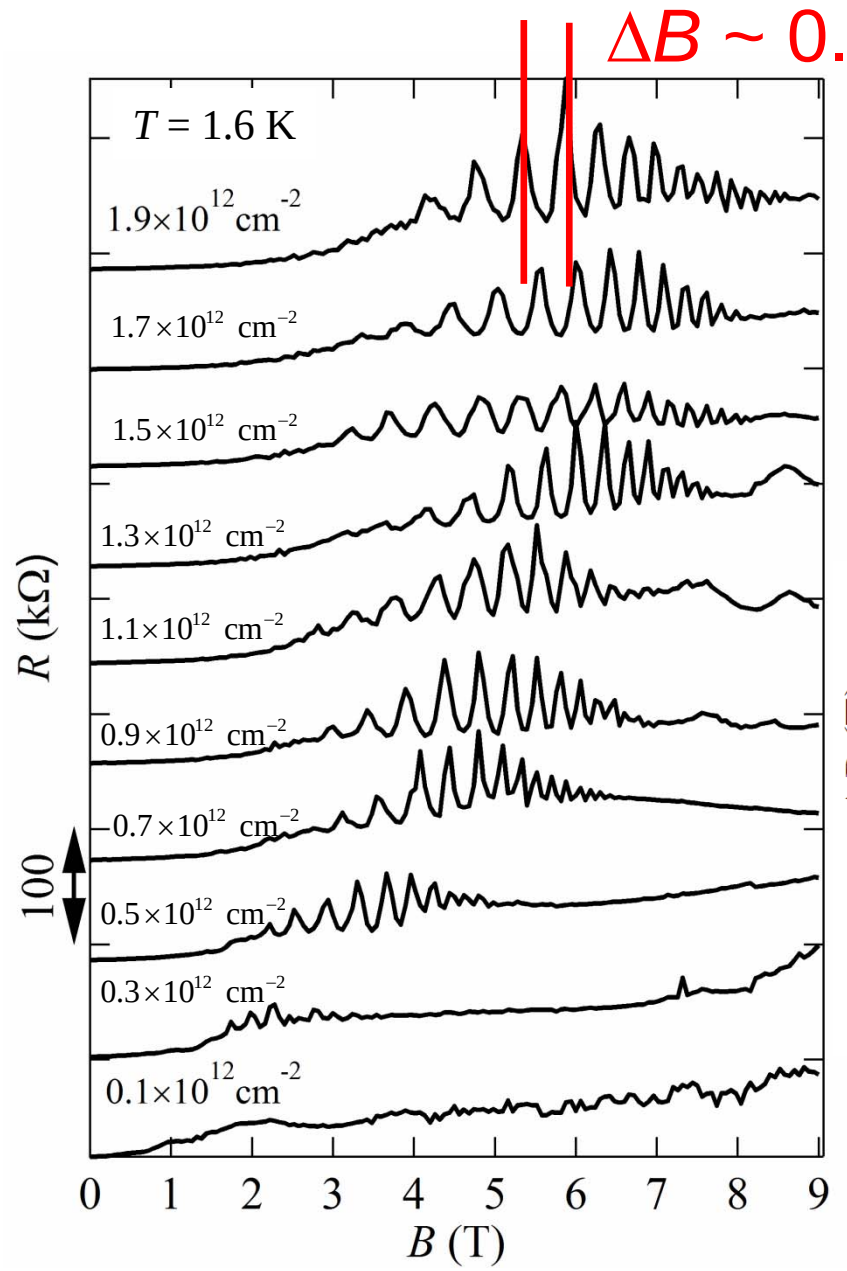


$$R = \frac{h}{e^2}\left(\frac{2}{\nu} + \frac{1}{\nu'}\right) \quad \text{for full mixing}$$

$$R > \frac{h}{e^2}\left(\frac{2}{\nu} + \frac{1}{\nu'}\right) \quad \text{for adiabatic}$$

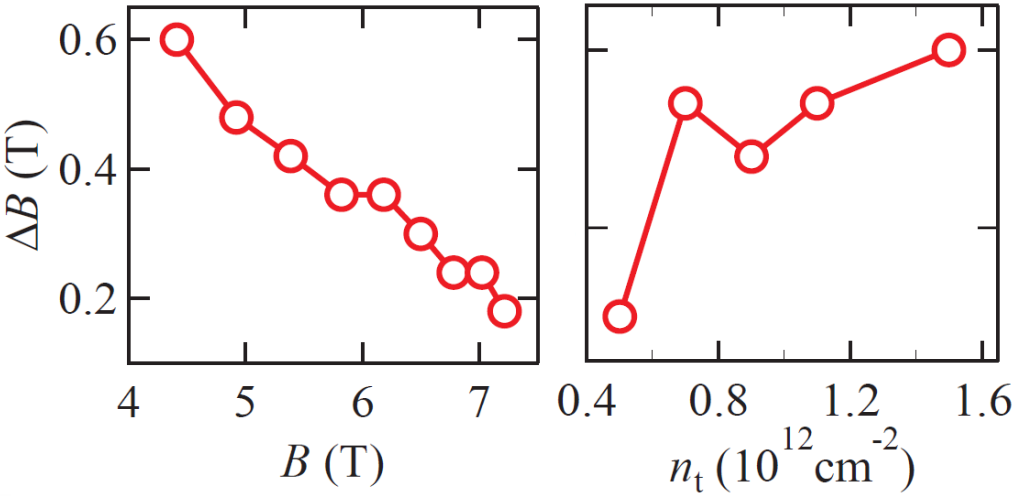


n-p-n quantum Hall junctions

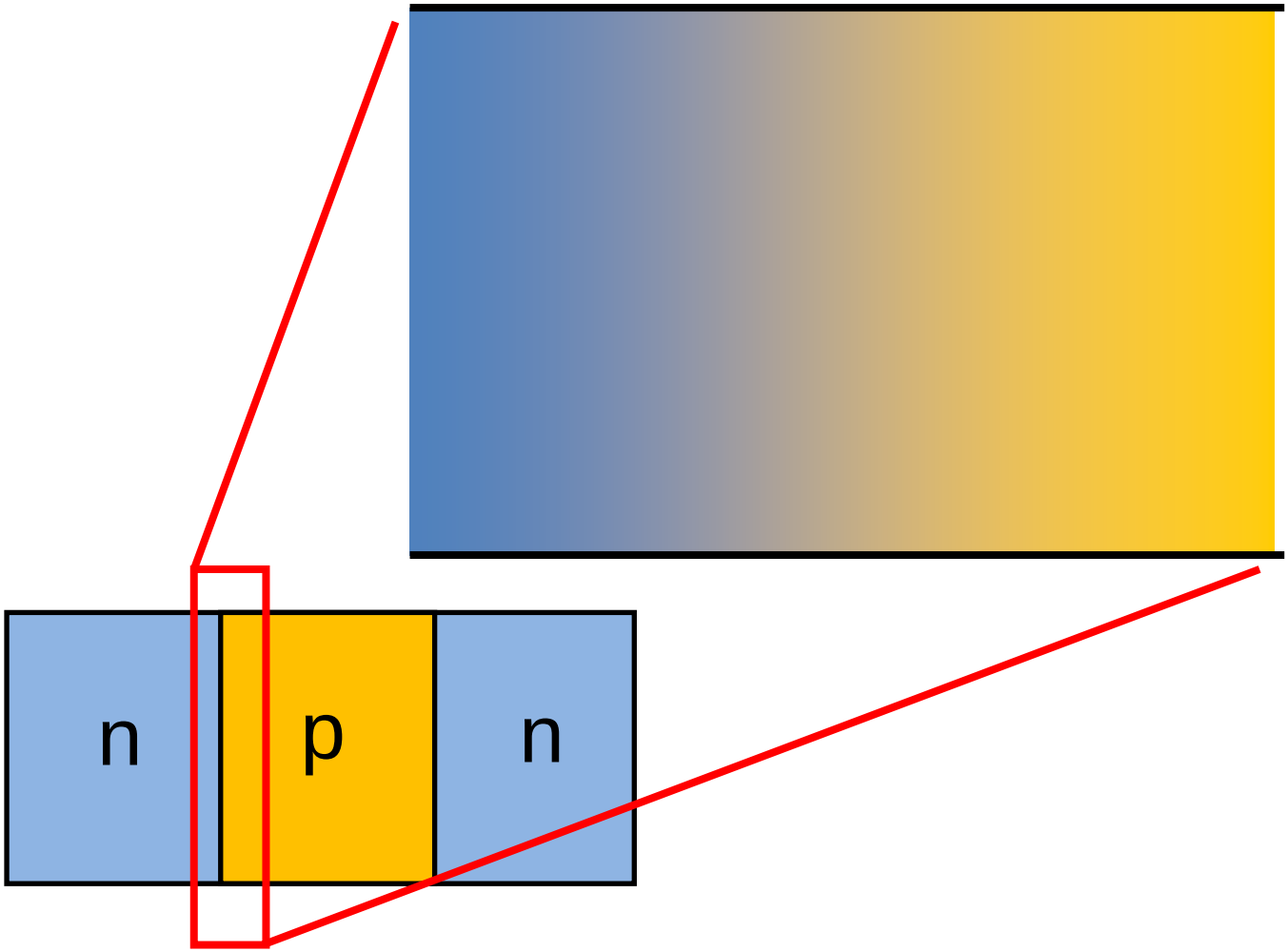


Aharonov-Bohm effect

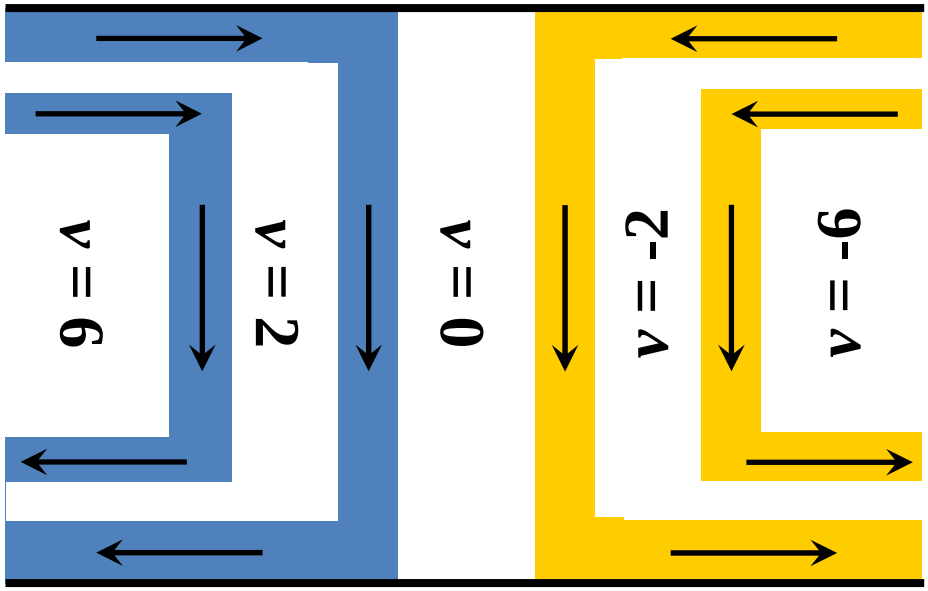
$$\Delta B = \frac{h}{e}\frac{1}{S}$$

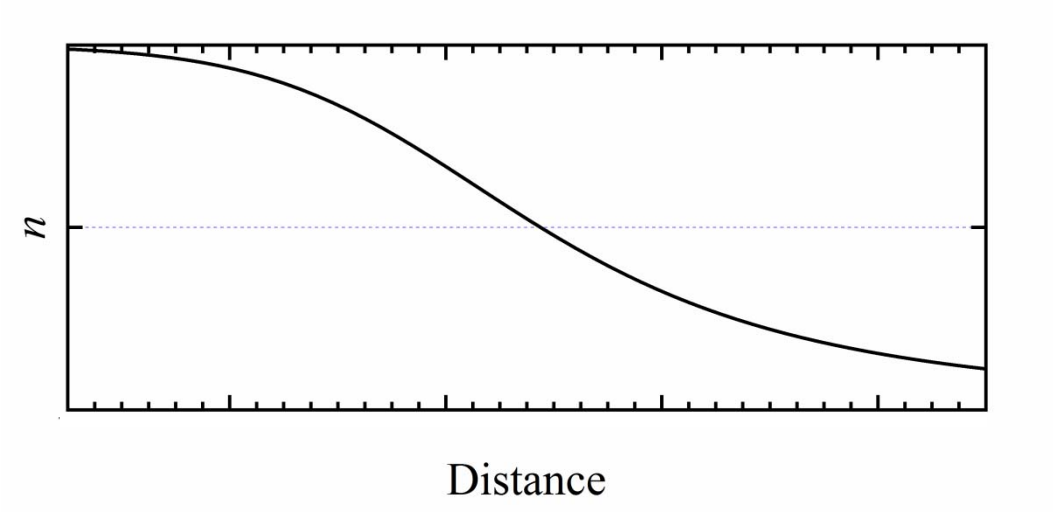


Carrier density profile at n-p junctions

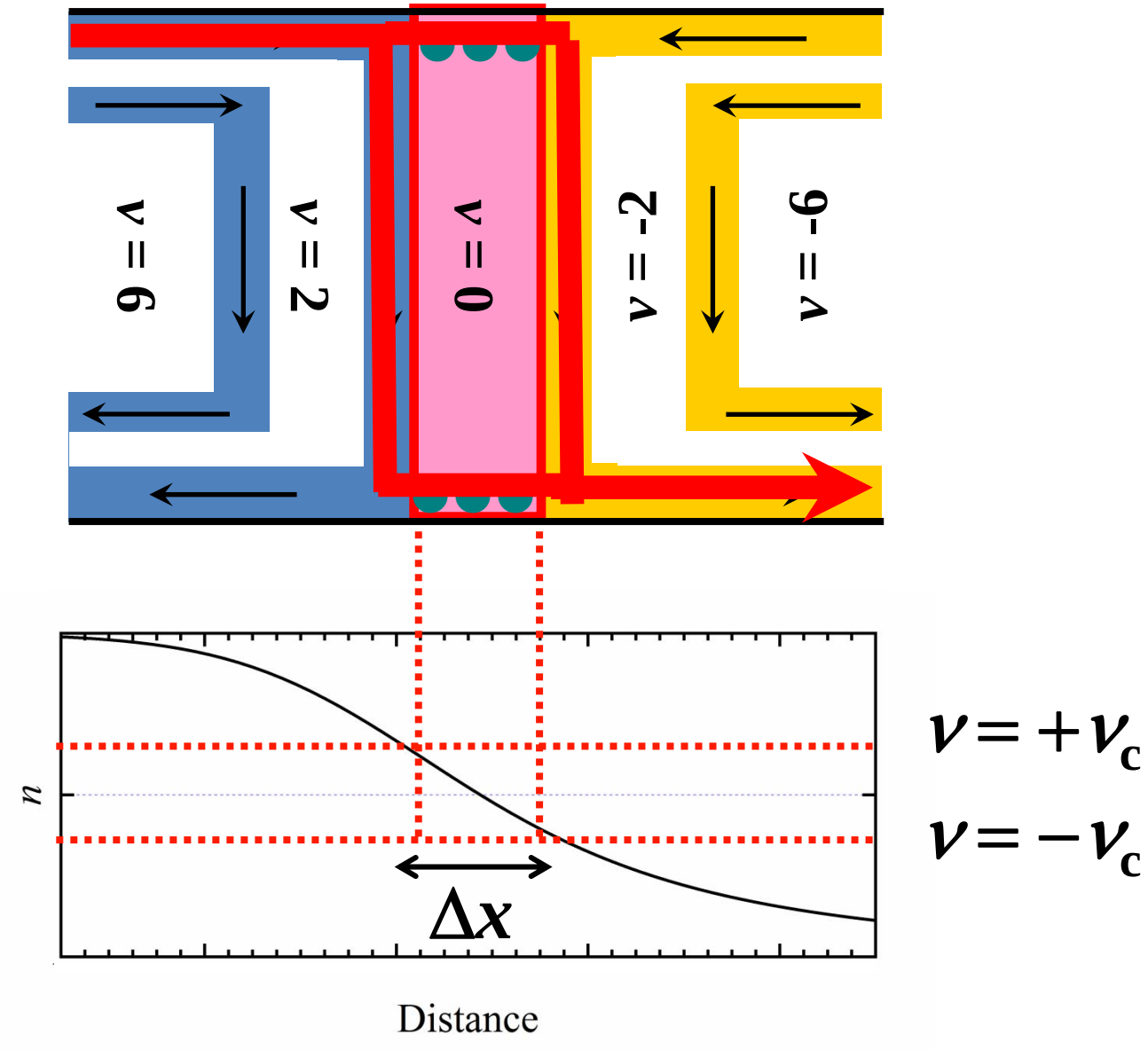


Carrier density profile at n-p junctions





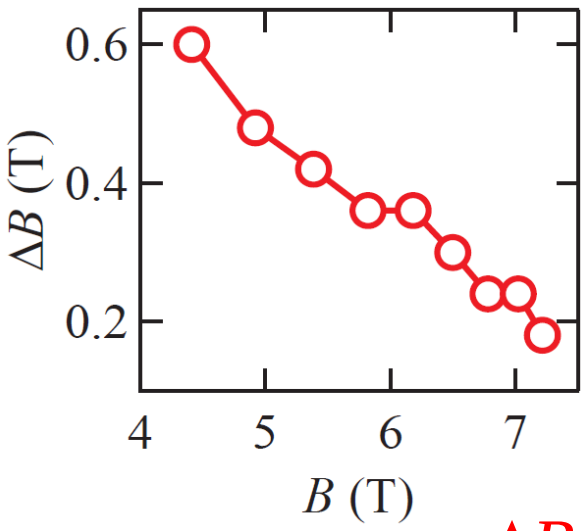
Carrier density profile at n-p junctions

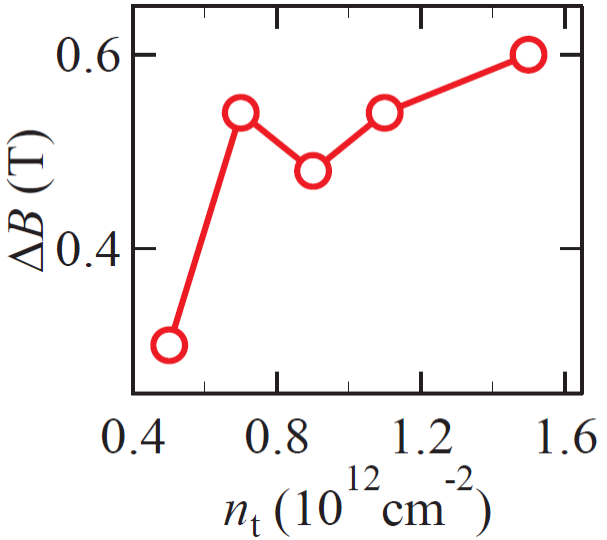


$\nu = +\nu_c$

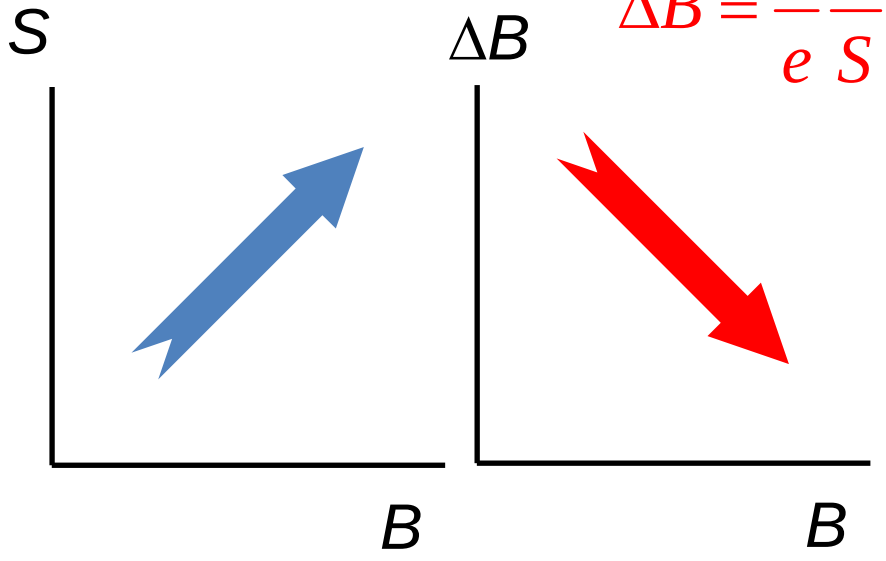
$\nu = -\nu_c$

$\nu = 0$ incompressible strip

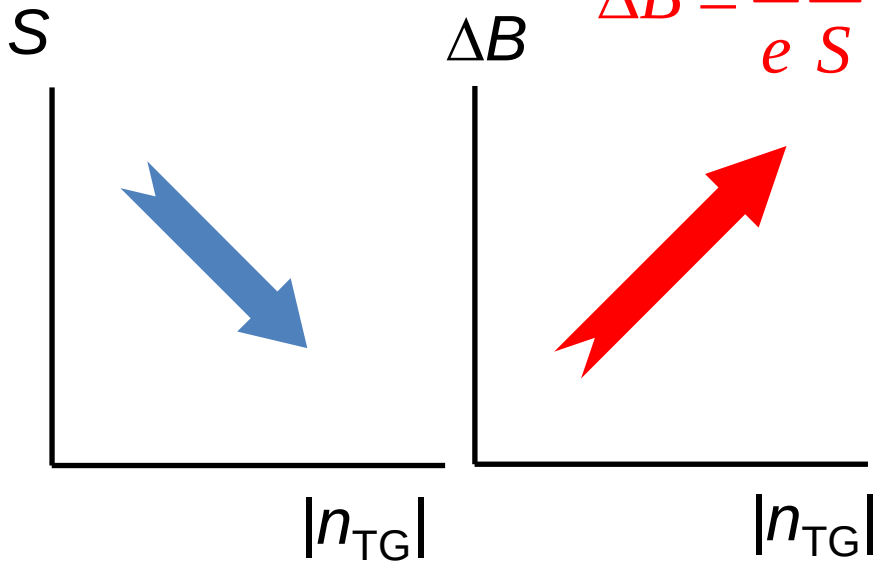




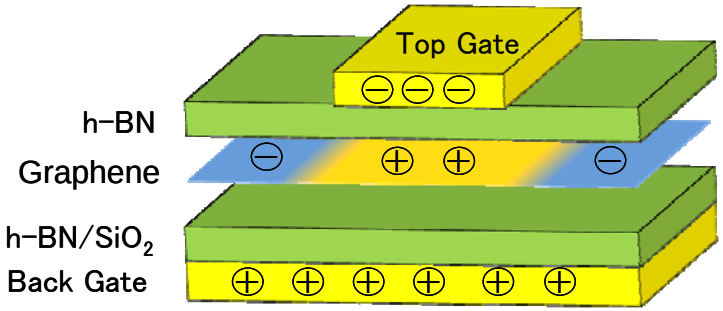
$$\Delta B = \frac{h}{e}\frac{1}{S}$$

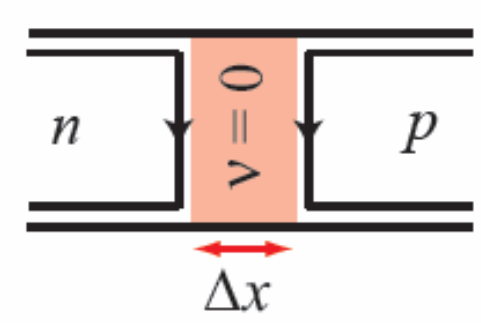


$$\Delta B = \frac{h}{e}\frac{1}{S}$$

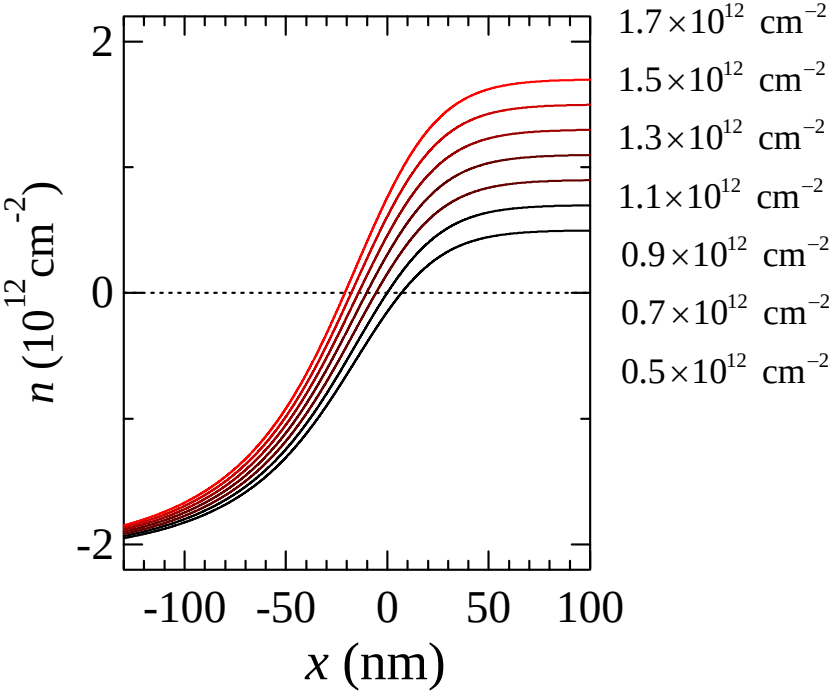


Local carrier density profile by FEM analysis

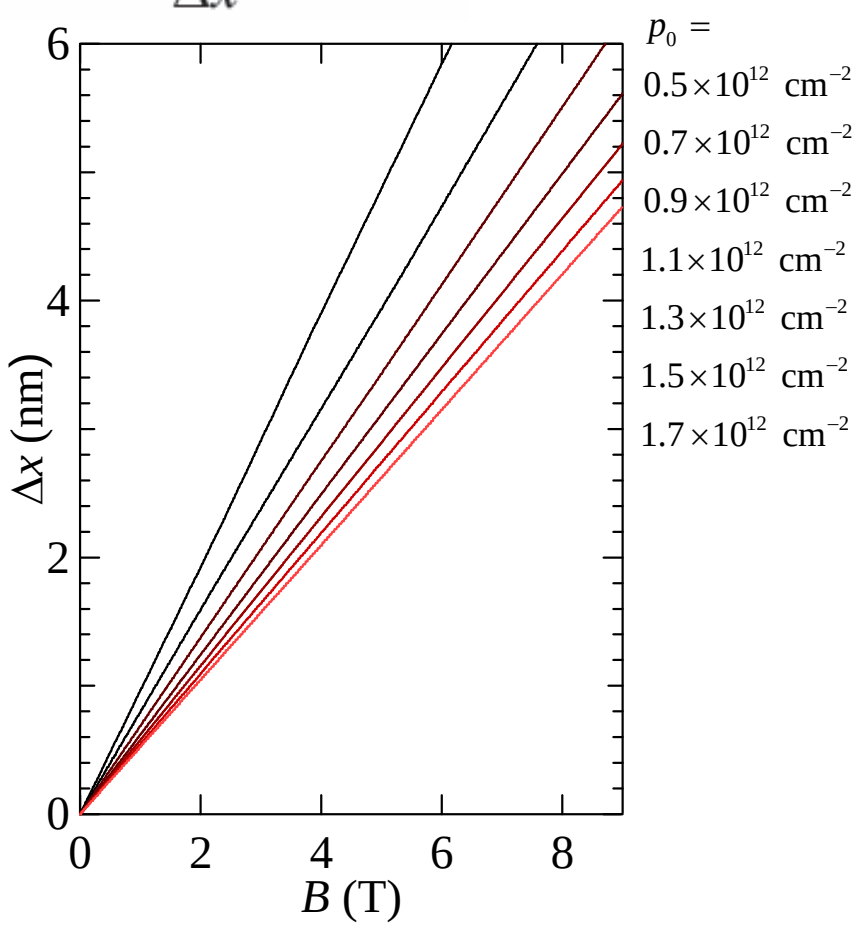




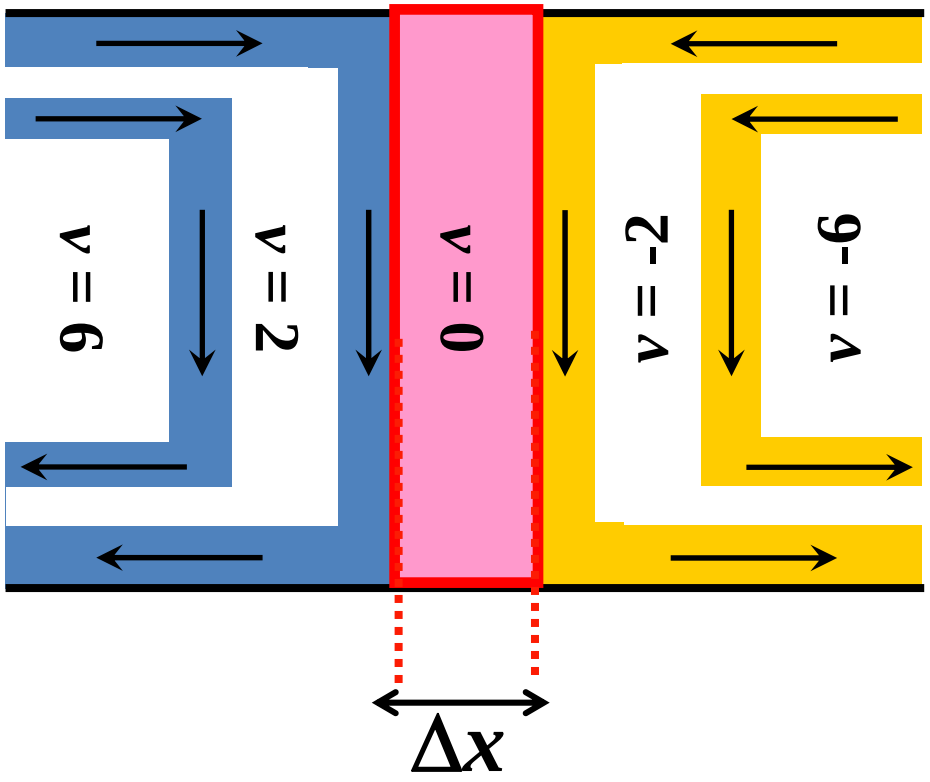
$$|\nu| \le \nu_c = 0.4$$

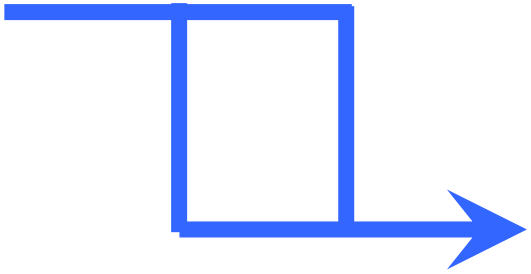


Finite element method
(Infolytica Elecnet)



Carrier density profile at n-p junctions

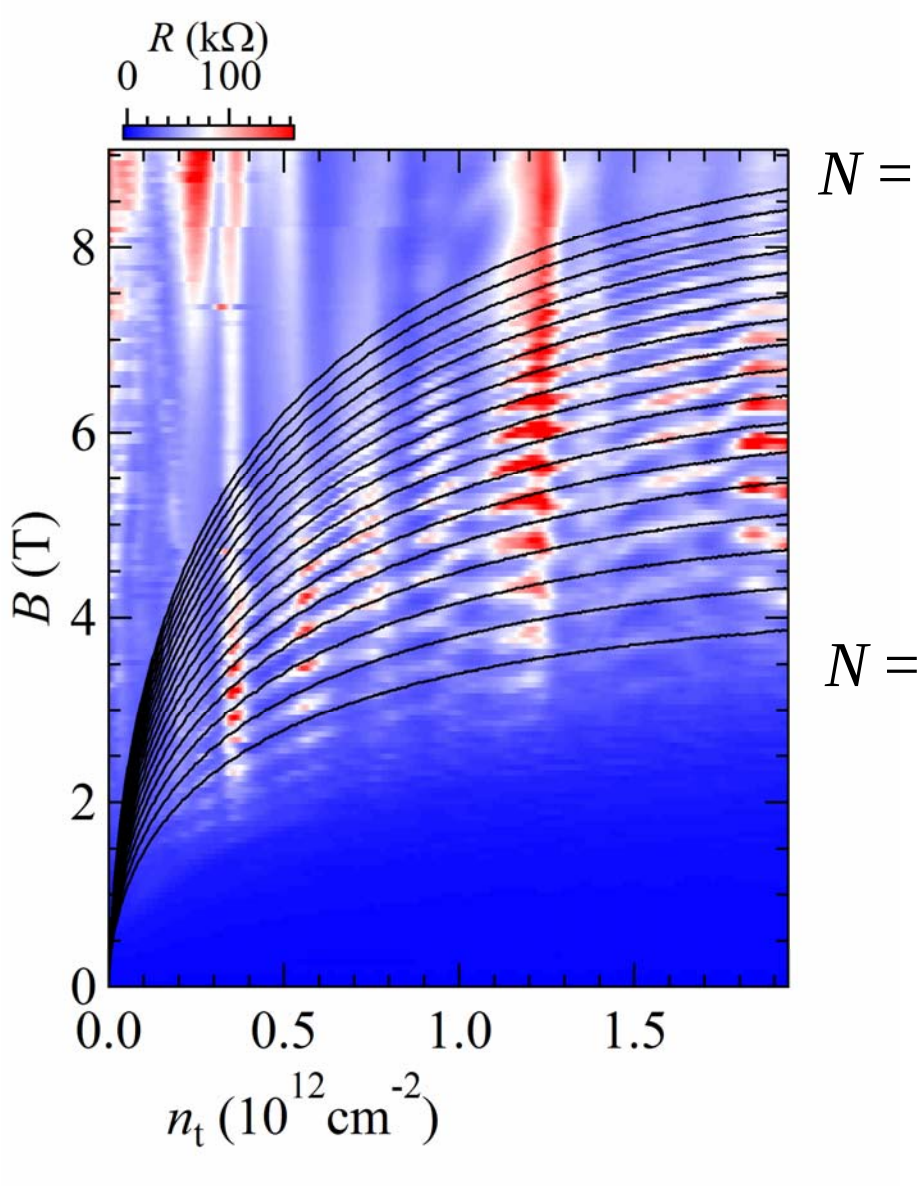




$$BW\,\Delta x\left(B, n, p\right) = N\phi_0$$

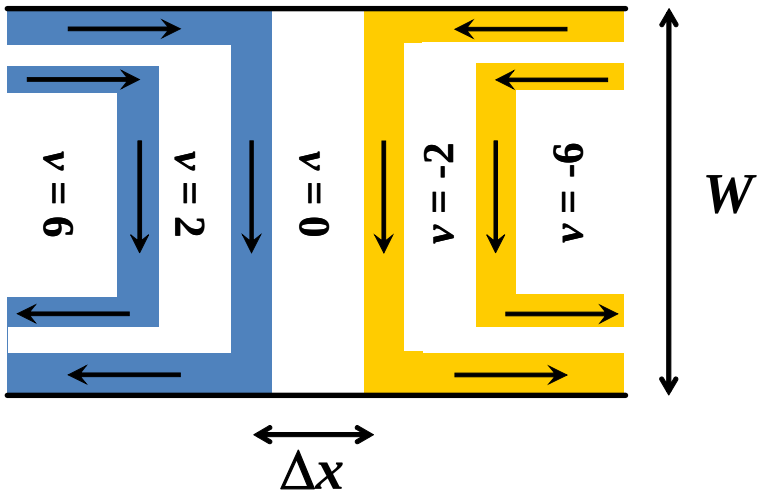
$(N = 1, 2, \ldots, 10, \ldots)$

Resistance oscillations



$N = 20$

$N = 4$



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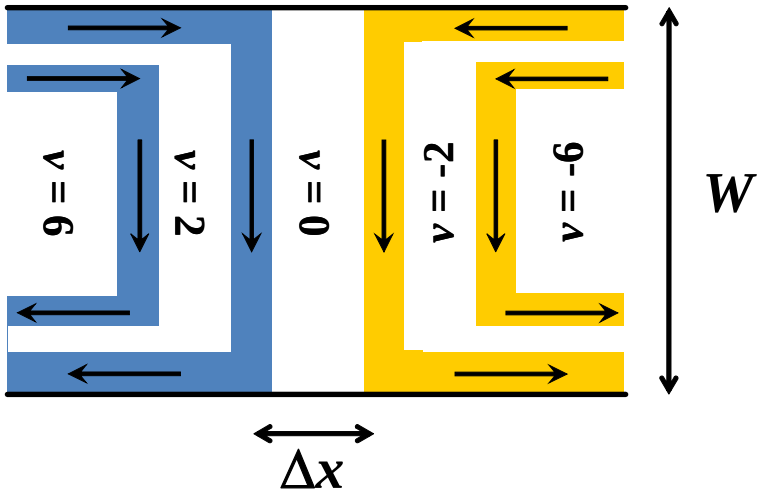
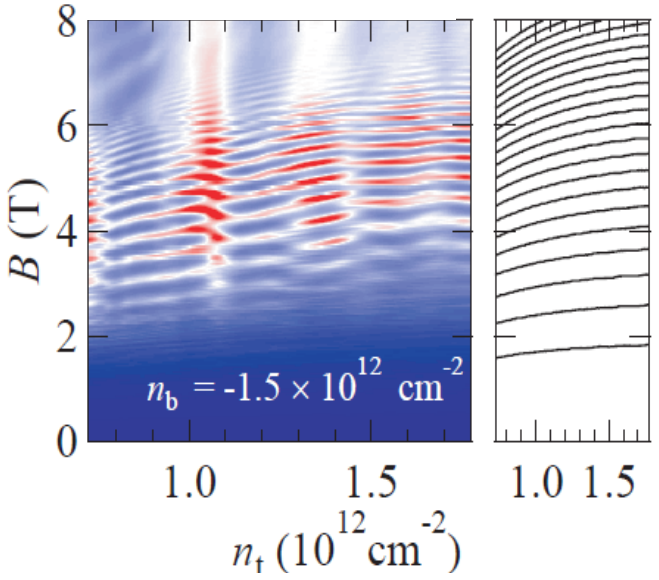
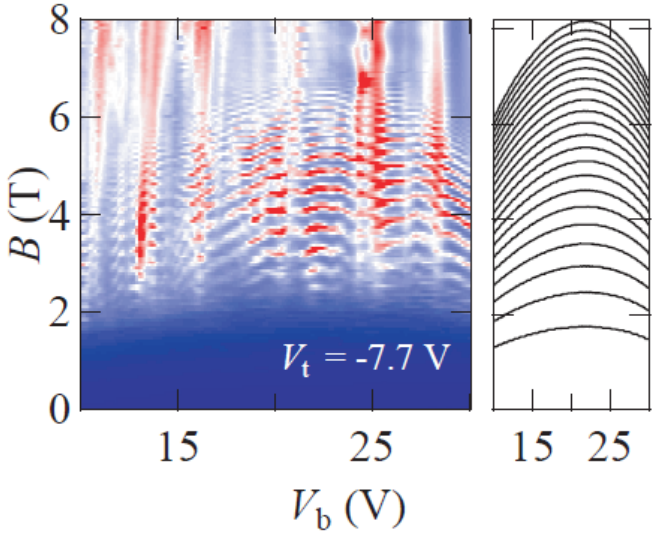
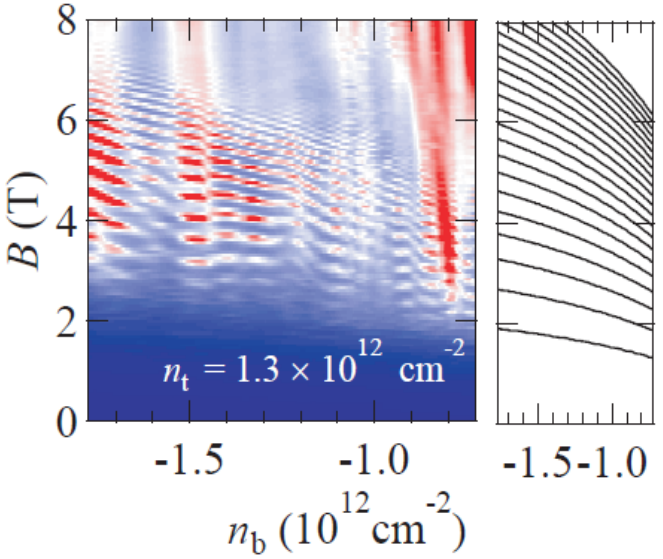
Resistance oscillations





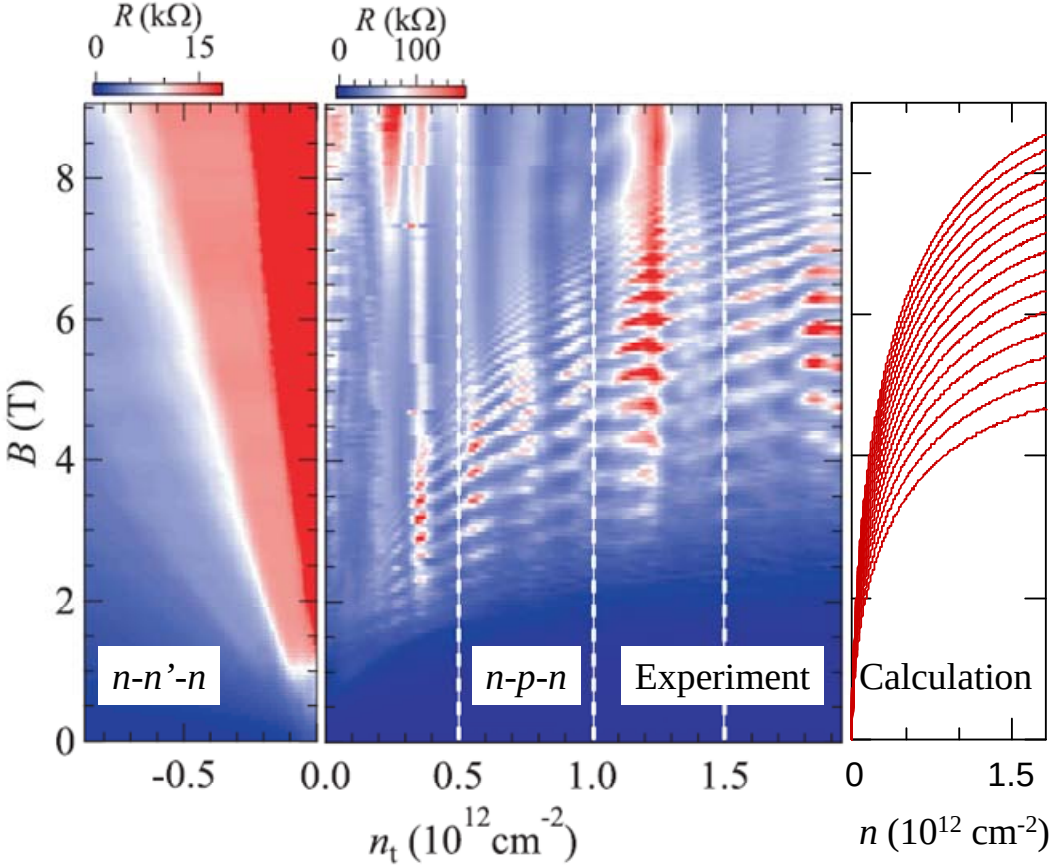


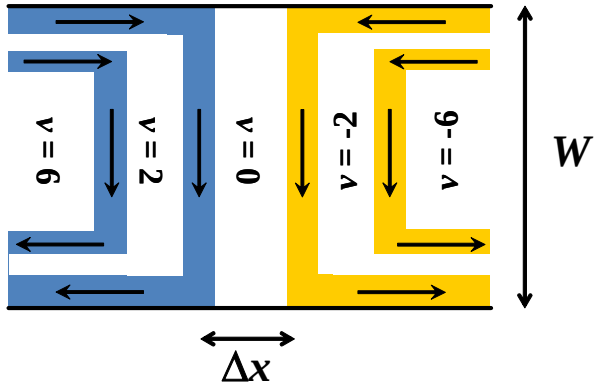


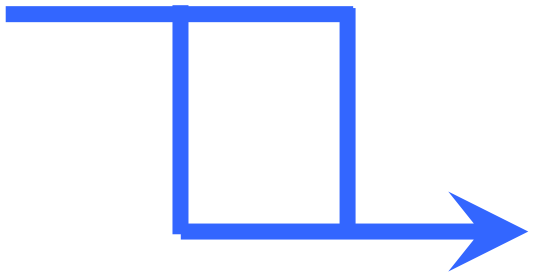
Novel oscillations in quantum Hall pn junctions

Quantum Hall pnp junctions

Magnetic flux quantization in $\nu = 0$ incompressible strip formed between co-propagating quantum Hall edge channels







Collaborators

Satoru Masubuchi, Sei Morikawa

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(National Institute of Materials Science)

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(Saitama University)

Summary

Transfer technique of atomic layers

Quantum Hall pnp junctions

- Novel magnetoresistance oscillations
- Coherent interference in QH edge channels

Graphene/h-BN

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- Magnetoresistance effect

$Fe_{0.25}TaS_2/Fe_{0.25}TaS_2$

Josephson junctions

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