Magnetoresistance of double layer hybrid system in a tilted magnetic field

Reza Asgari

asgari@ipm.ir

Institute for Research in Fundamental Sciences

Quantum transport in graphene, (in *Memory of Malek Zareyan*), IPM, 24th April 2014

In collaboration with

Fariborz Parhizgar

Outlook

1. Introduction

    brief overview on Boltzmann approach

2. Electronic structure and model Hamiltonian

    Magnetoresistance @ in-plane magnetic field

    Effective potential in double layer system

    Electromagnetic in two-component systems

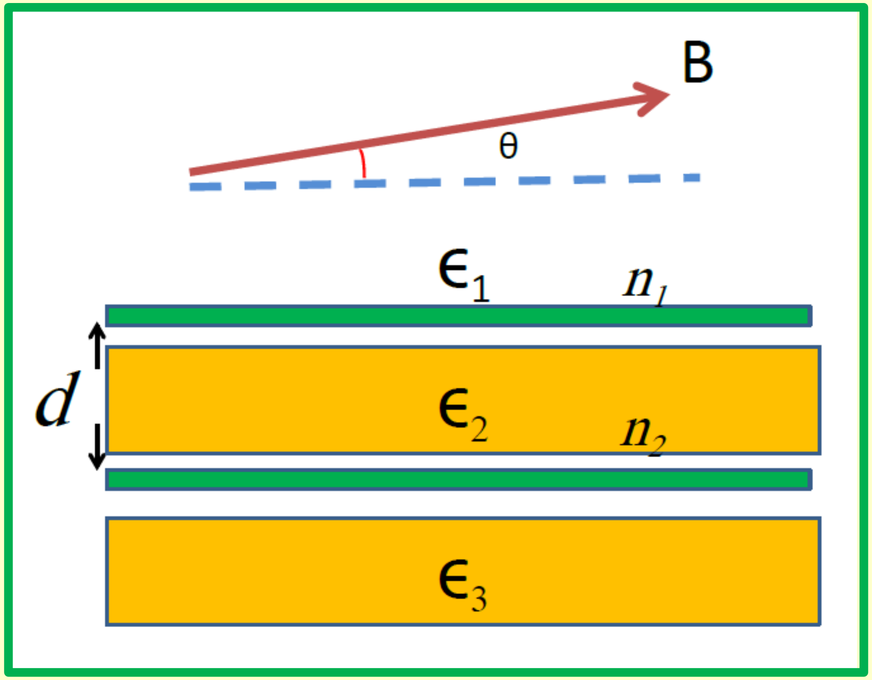
    In plane and Hall resistance in tilted field

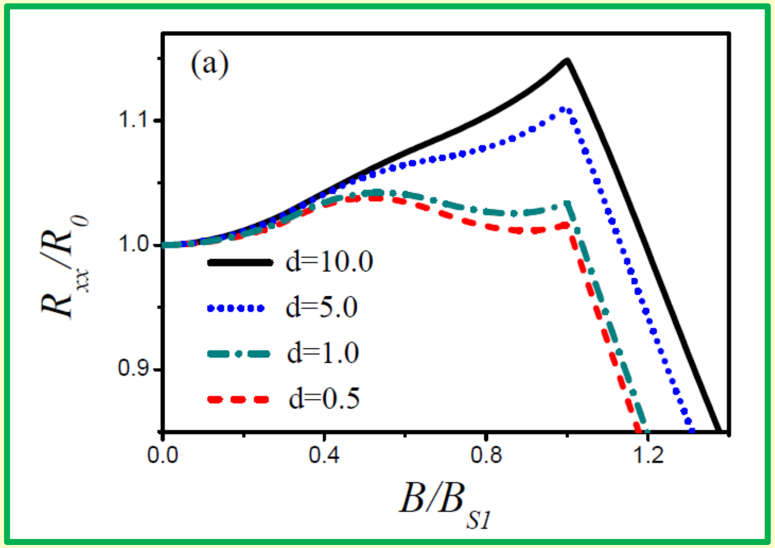
3. Conclusion

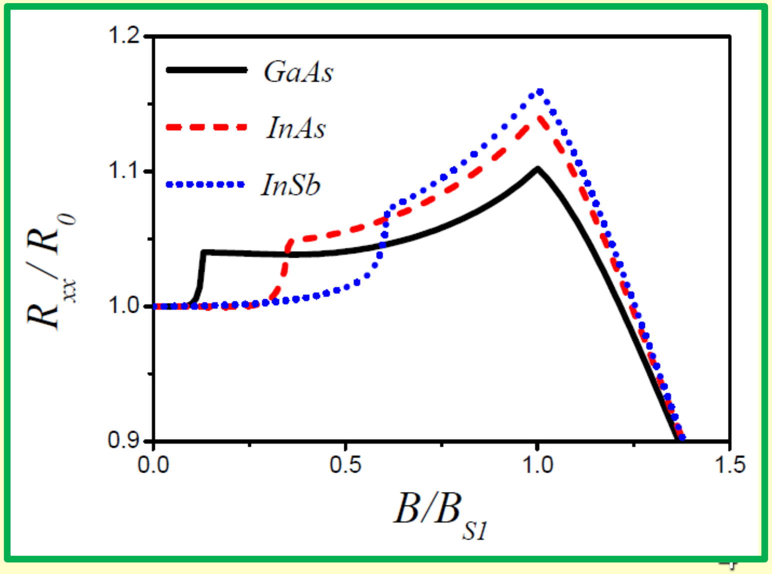
    Giant Hall resistance

    tailoring the negative magnetoresistance

My purpose I:Magnetoresistance

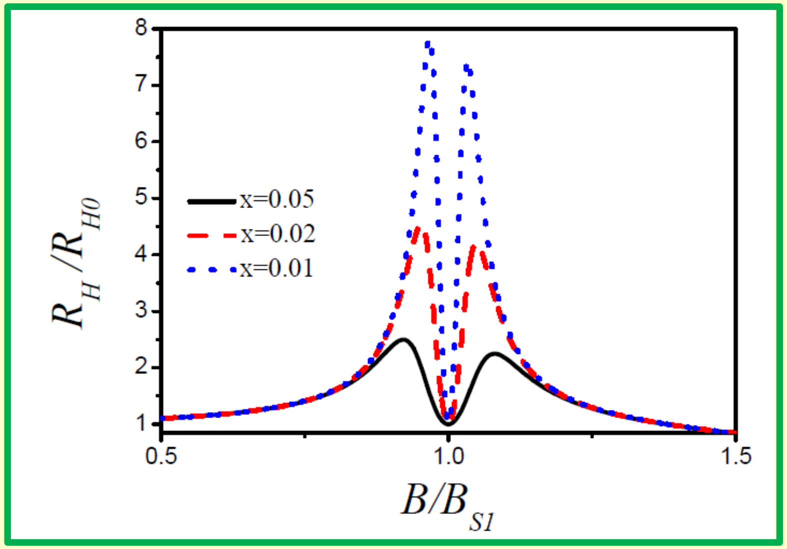


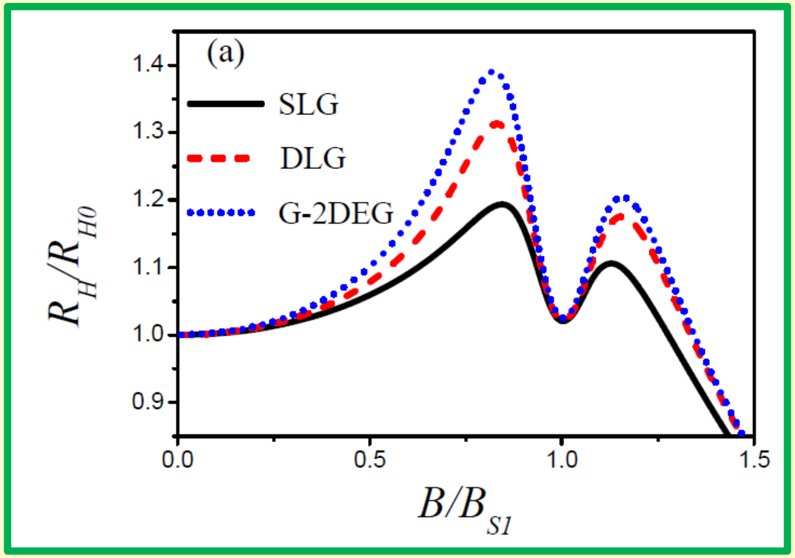




Parhizgar, Asgari arXiv:1403.2857

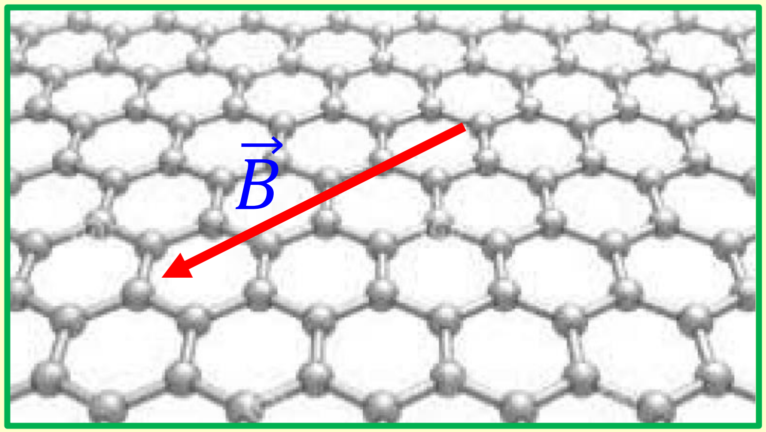
My purpose II:Hall resistance



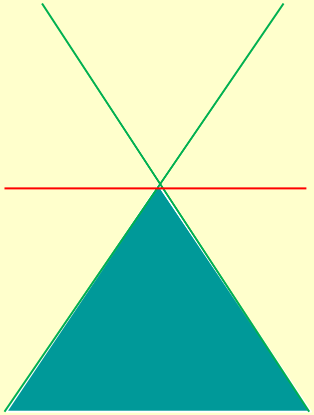


Parhizgar, Asgari arXiv:1403.2857

Undoped graphene in the presence of in-plane magnetic field

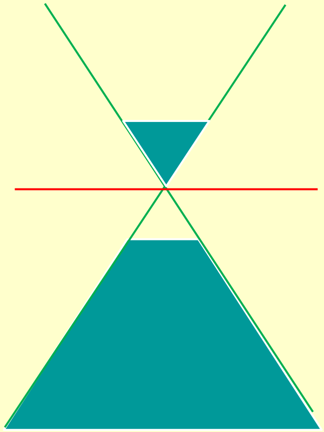


$\vec{B} = 0$



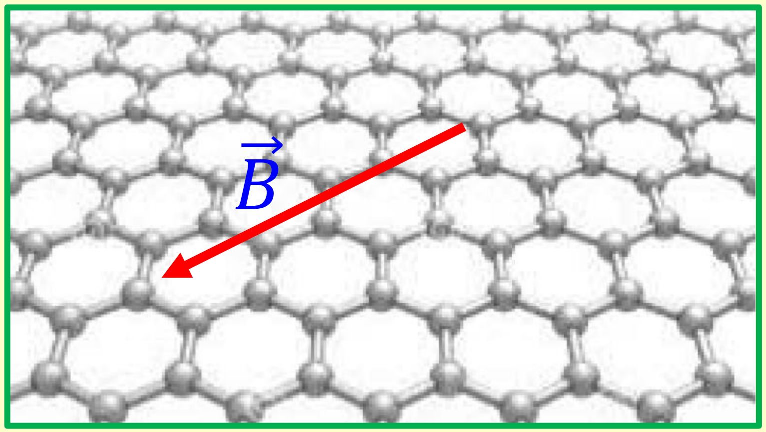
$$n = p = \frac{g_v}{16\pi}\left(\frac{g^* \mu_B B}{\hbar v_F}\right)^2$$

$\vec{B} \neq 0$



Hwang and Das Sarma , Phys. Rev. B **80**, 075417 (2009)

Doped graphene in the presence of in-plane magnetic field

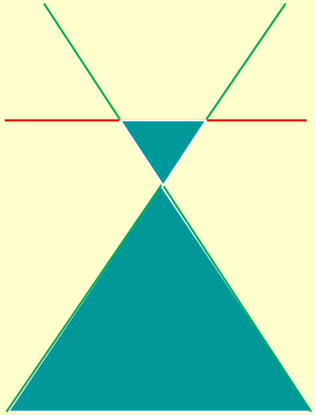


$$n^{\pm} = \frac{g_v}{4\pi\hbar^2 v_F^2}\left(\mu \pm \frac{1}{2} g^* \mu_B B\right)^2$$

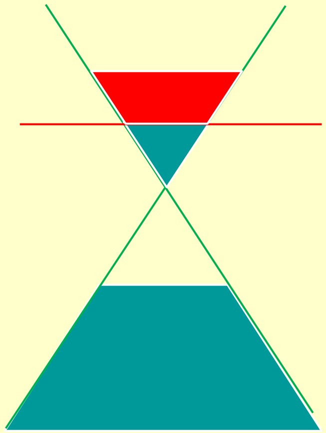
$$n = n^+ + n^-$$

$$\zeta = \frac{n^+ - n^-}{n}$$

$\vec{B} = 0$



$\vec{B} \neq 0$



Hwang and Das Sarma , Phys. Rev. B **80**, 075417 (2009)

Boltzmann approach in graphene

$$\sigma^{\pm} = \frac{e^2}{2}\hbar^2 v_F^2 \int d\varepsilon D^{\pm}(\varepsilon)\tau(\varepsilon^{\pm})\left[-\frac{\partial n_F(\varepsilon)}{\partial \varepsilon}\right]$$

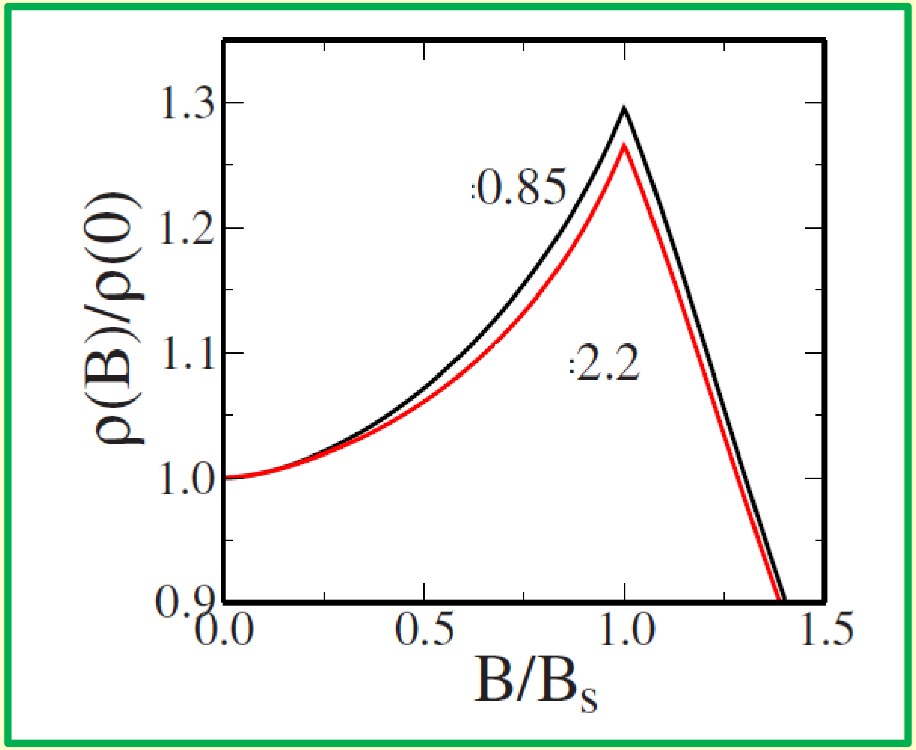
$$\frac{1}{\tau(\varepsilon_k)} = \frac{\pi}{\hbar}\sum_{k'} n_i \left|\frac{v(q)}{\varepsilon(q)}\right|^2 (1-\cos^2(\theta))\,\delta(\varepsilon_k - \varepsilon_{k'})$$

$$\varepsilon(q,\omega=0) = 1 - v(q)\chi(q,\omega=0)$$

$$q = |k-k'| \quad \vartheta = \vartheta_k - \vartheta_{k\prime}$$

J. M. Ziman, *Principles of the theory of Solids*, Cambridge, (1972)

Magnetoresistance: monolayer

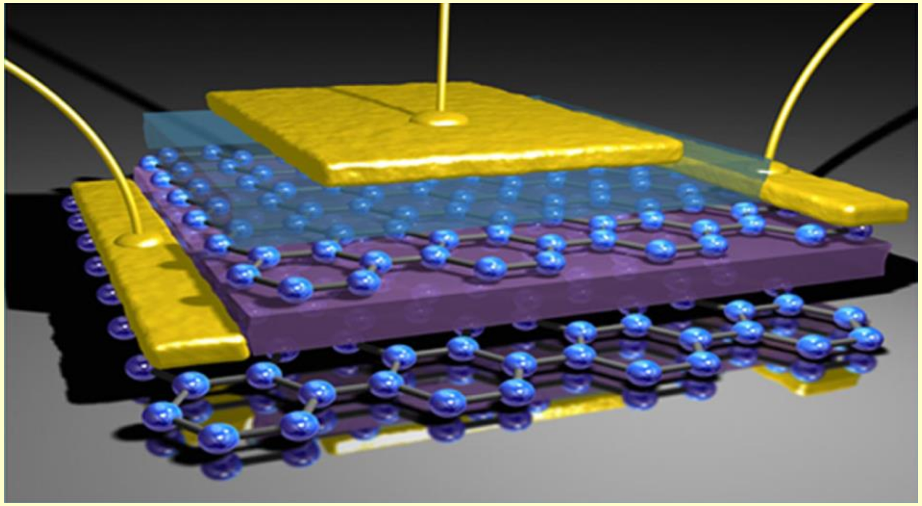


$$\alpha_{ee} = \frac{e^2}{\hbar v_F \varepsilon_r}$$

$$B_s \sim 140\sqrt{n}\ [T]$$

Hwang and Das Sarma , Phys. Rev. B **80**, 075417 (2009)

Hybrid system



A. K. Geim and I . V. Grigoieva, Nature, **499**, 419 (2013)

Effective interactions

$$W(q) = \epsilon(q)^{-1}\mathcal{V}_{ei}(q) = (1 + \mathcal{W}(q)\chi(q))^{-1}\mathcal{V}_{ei}(q)$$

$$\chi(q)^{-1} = \chi^0(q)^{-1} - \mathcal{W}(q)$$

$$\mathcal{W}(q) = \begin{pmatrix} V_{11} & V_{12} \\ V_{21} & V_{22} \end{pmatrix}$$

$$\chi^0(q) = \begin{pmatrix} \Pi_1^0(q) & 0 \\ 0 & \Pi_2^0(q) \end{pmatrix}$$

$$\frac{1}{\tau^\pm} = \frac{8n_i}{2\pi\hbar}\frac{E_F^\pm}{\gamma^2}\int_0^1 dy|W(2k_F^\pm y)|^2 y^2\sqrt{(1-y^2)}$$

Effective interactions

$$W_{11}(q) = \frac{V_{11}(q) + [V_{12}^2(q) - V_{11}(q)V_{22}(q)]\Pi_2^0(q)}{\varepsilon(q)}$$

$$\varepsilon(q) = [1 - V_{11}(q)\Pi_1^0(q)][1 - V_{22}(q)\Pi_2^0(q)] \\ -V_{12}^2(q)\Pi_1^0(q)\Pi_2^0(q)$$

$$V_{11}(q) = \frac{4\pi e^2}{qD(q)}[(\epsilon_2 + \epsilon_3)e^{qd} + (\epsilon_2 - \epsilon_3)e^{-qd}]$$

$$V_{12}(q) = V_{21}(q) = \frac{8\pi e^2}{qD(q)}\epsilon_2$$

$$D(q) = [(\epsilon_1 + \epsilon_2)(\epsilon_2 + \epsilon_3)e^{qd} + (\epsilon_1 - \epsilon_2)(\epsilon_2 - \epsilon_3)e^{-qd}]$$

Electromagnetic

$$\mathbf{E} = \frac{1}{\sigma_+}(\mathbf{J}_+ + \beta_+ \mathbf{B} \times \mathbf{J}_+) = \frac{1}{\sigma_-}(\mathbf{J}_- + \beta_- \mathbf{B} \times \mathbf{J}_-)$$

$$\beta_i = e\tau_i v_F / \hbar k_{\mathrm{F},i} c, \quad i = \pm$$

$$\mathbf{J_i} = \alpha_1^i \mathbf{E} + \alpha_2^i \mathbf{B} \times \mathbf{E}$$

$$\mathbf{J} = \mathbf{J}_+ + \mathbf{J}_-$$

Electromagnetic

$$\mathbf{E} = R_{xx}\mathbf{J} + R_H \mathbf{B}\times\mathbf{J}$$

$$R_{xx} = a/(a^2 + b^2 B_\perp^2)$$

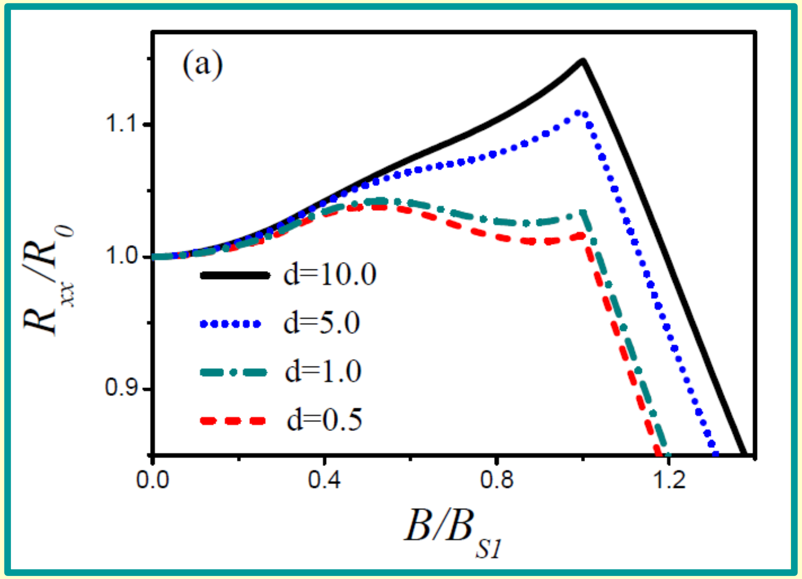
$$R_H = b/(a^2 + b^2 B_\perp^2)$$

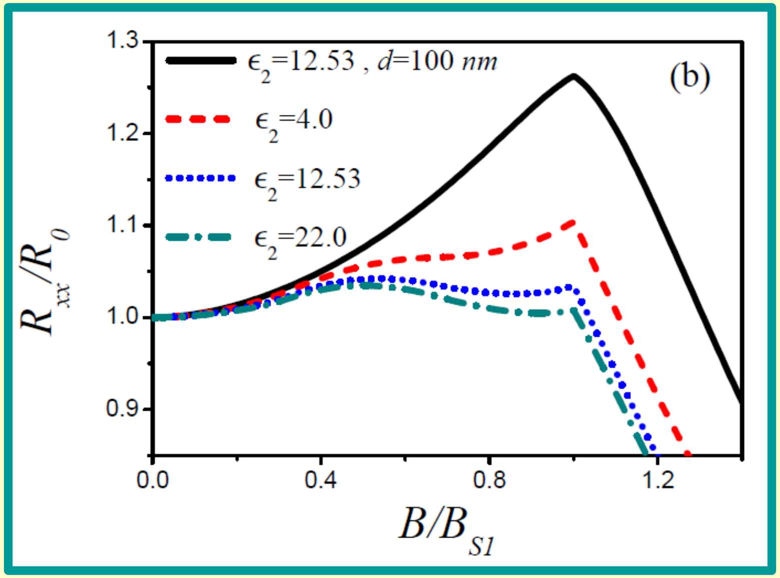
$$a = \sum_{i=+,-} \frac{\sigma_i}{1+\beta_i^2 B_\perp^2}$$

$$b = \sum_{i=+,-} \frac{\sigma_i \beta_i}{1+\beta_i^2 B_\perp^2}$$

$$\rho = \begin{pmatrix} \rho_1 & \rho_D \\ \rho_D & \rho_2 \end{pmatrix} = \frac{1}{\sigma_1\sigma_2 - \sigma_D^2}\begin{pmatrix} \sigma_2 & -\sigma_D \\ -\sigma_D & \sigma_1 \end{pmatrix}$$

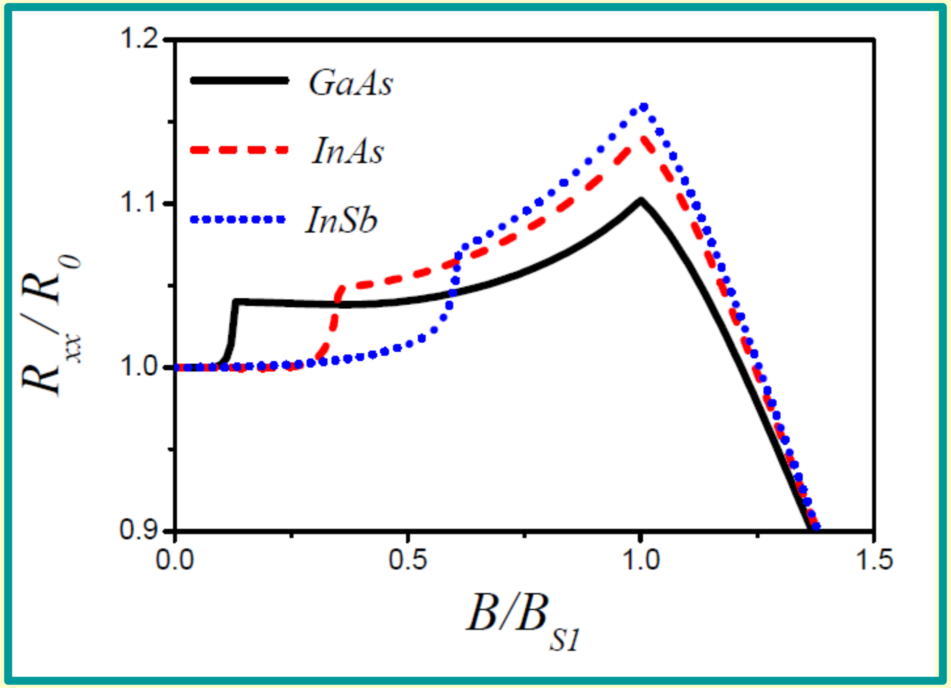
Longitudinal resistivity: graphene/graphene @in-plane B





Parhizgar, Asgari arXiv:1403.2857

Graphene/2DEG



$$B_{s2} \sim \frac{1}{m^*}$$

Hall coefficient

$$R_H = b/(a^2 + b^2 B_\perp^2)$$

$$B_\perp \beta_\pm = \frac{B I_0 n_t}{2 B_{S1} I^\pm \; n_{1\pm}} \; x = \alpha_\pm \; x$$

$$x = 0.895 \sin(\theta) \sqrt{\bar{n}_1} / \bar{n}_{imp} I_0$$

$$I^\pm = \frac{\sqrt{\pi(n_1+n_2)}}{4\pi^2 e^4} \int_0^1 dy y^2 \sqrt{1-y^2}\, W_{11}^2 (2k_F^\pm y)$$

$$B_{S1} = \hbar v_{\mathrm{F}} \sqrt{2\pi n_1} / (g^* \mu_B)$$

Hall coefficient

$x \to 0$ and $\alpha_- \to \infty$

$x\alpha_- \to 0$

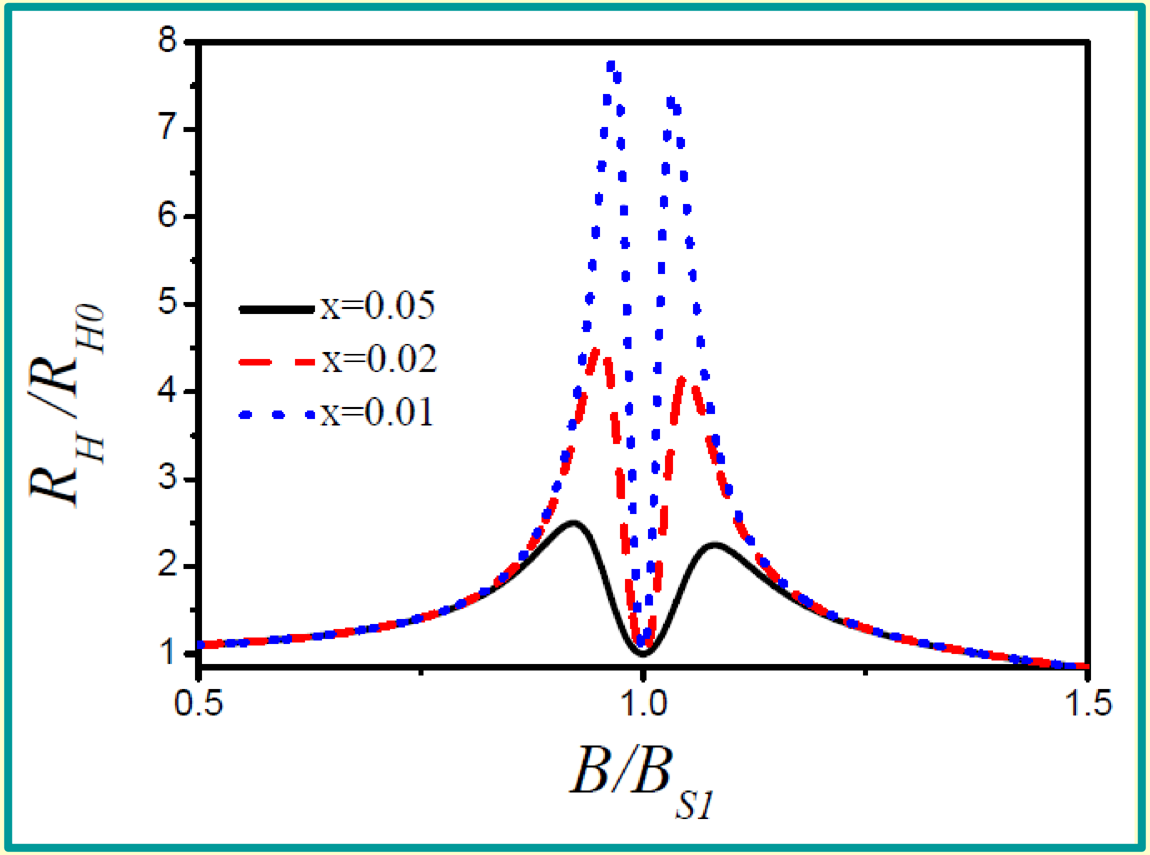
$$\frac{R_H}{R_{H0}} = \frac{D\sigma_0}{\beta_0} \frac{\sigma_+\beta_+ + \sigma_-\beta_-}{(\sigma_+ + \sigma_-)^2 + x^2(\sigma_+\alpha_+ + \sigma_-\alpha_-)^2} = \frac{n_1 I_0^2}{4n_\pm I_\pm^2}$$

$x \to 0$ and $\alpha_- \to \infty$

$x\alpha_- \to \infty$

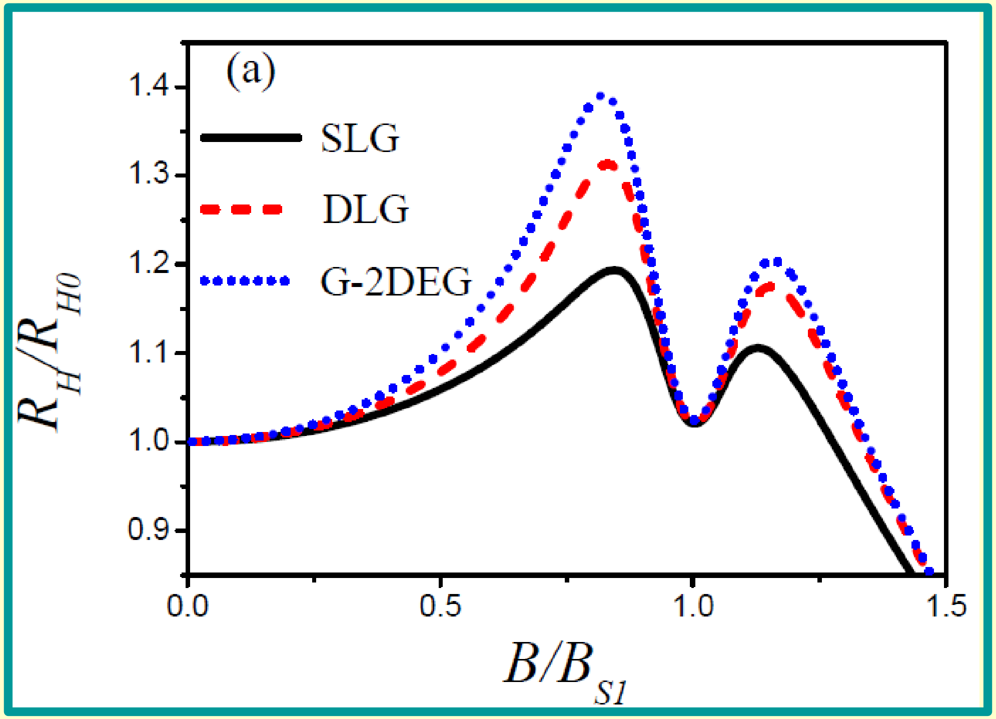
$$\frac{R_H}{R_{H0}} = \frac{\sigma_0\beta_+}{\sigma_+\beta_0} = \frac{n_1}{n_+}$$

Hall coefficient: graphene/graphene



Parhizgar, Asgari arXiv:1403.2857

Hall coefficient: graphene/2DEG



Parhizgar, Asgari arXiv:1403.2857

Thanks for your attention