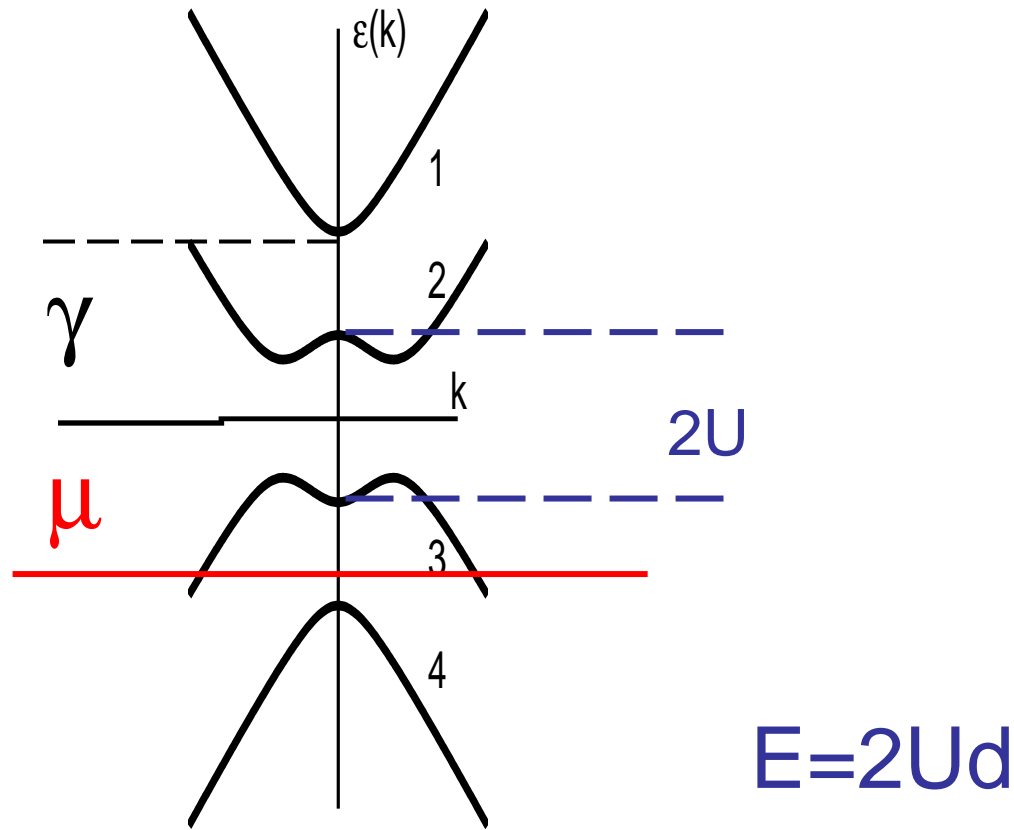


Screening in gated bilayer graphene

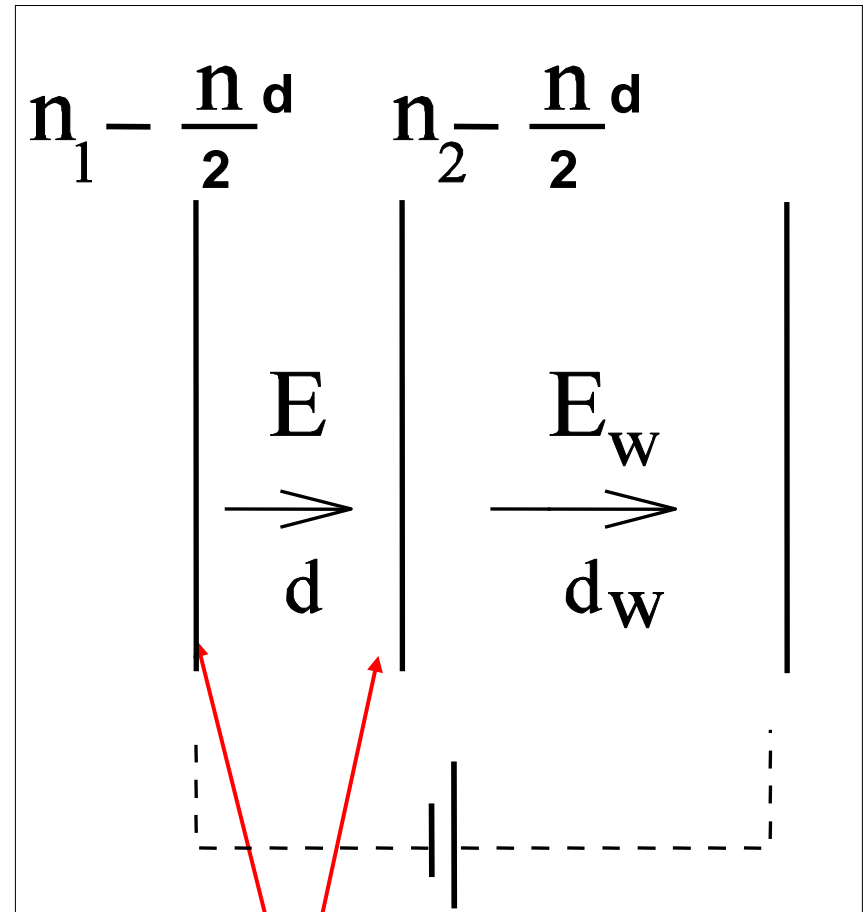
L. Falkovsky

Bilayer electron dispersion



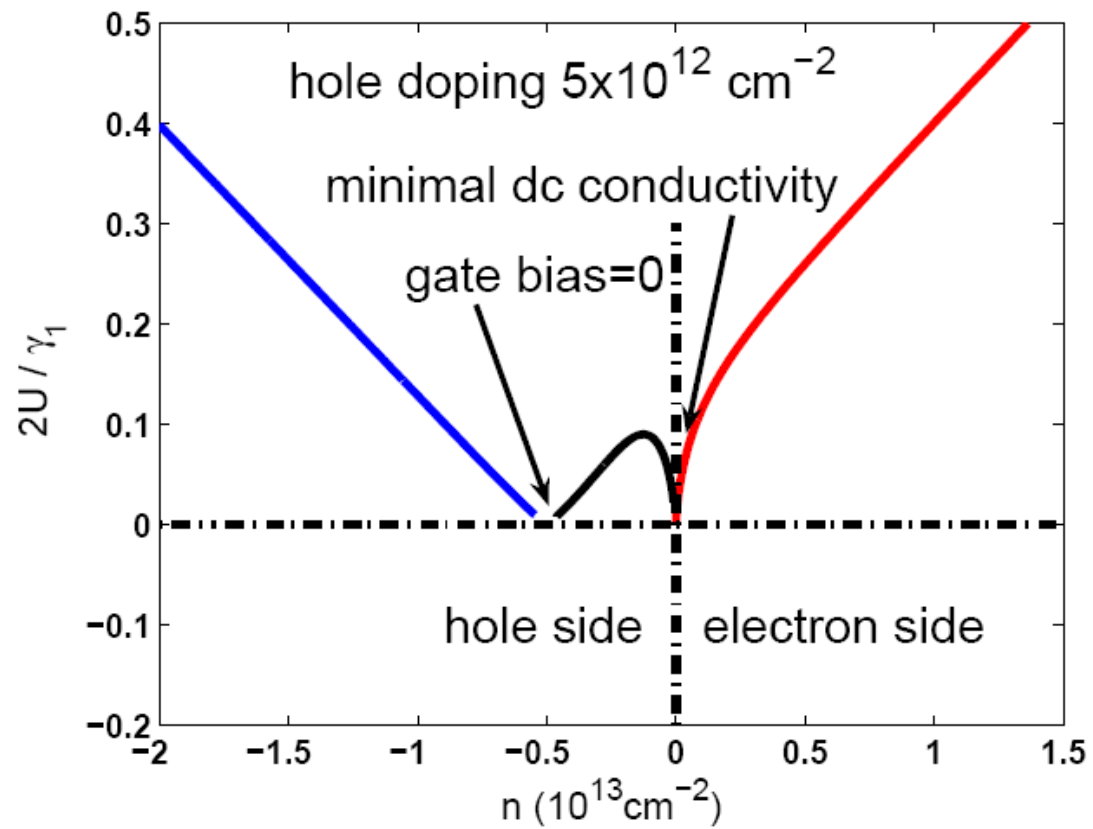
McCann, Fal'ko (2006-2007)

Field effect



Novoselov et al
Ohta et al
Li et al
Kuzmenko et al
Mak et al

The gap versus the carrier concentration



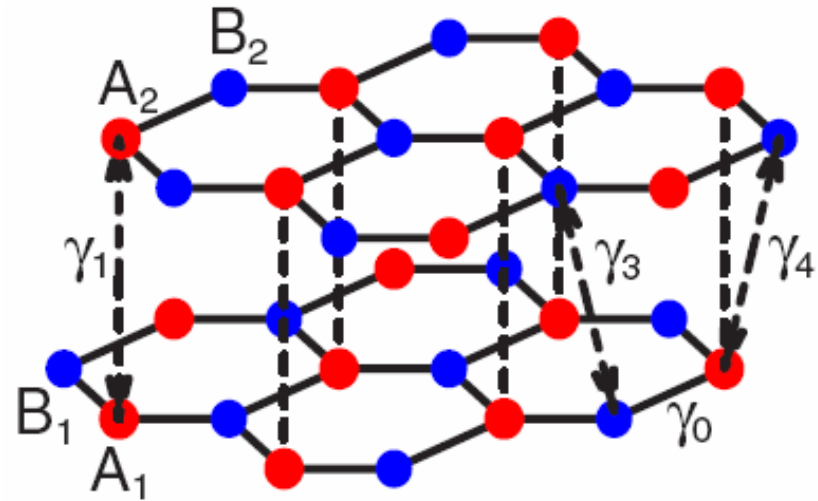
Tight-binding approximation

$$\psi_a = \frac{1}{\sqrt{N}} \sum_j e^{i\mathbf{k}\mathbf{a}_j} \psi_0(\mathbf{a}_j - \mathbf{r})$$

$$\psi_b = \frac{1}{\sqrt{N}} \sum_j e^{i\mathbf{k}\mathbf{a}_j} \psi_0(\mathbf{a}_j + \mathbf{a} - \mathbf{r})$$

$$\psi_{a1} = \frac{1}{\sqrt{N}} \sum_j e^{i\mathbf{k}\mathbf{a}_j} \psi_0(\mathbf{a}_j + \mathbf{c} - \mathbf{r})$$

$$\psi_{b1} = \frac{1}{\sqrt{N}} \sum_j e^{i\mathbf{k}\mathbf{a}_j} \psi_0(\mathbf{a}_j + \mathbf{c} + \mathbf{a} - \mathbf{r}),$$



Effective Hamiltonian

$$H(\mathbf{k}) = \begin{pmatrix} U & vk_+ & \gamma_1 & 0 \\ vk_- & U & 0 & 0 \\ \gamma_1 & 0 & -U & vk_- \\ 0 & 0 & vk_+ & -U \end{pmatrix}$$

Carrier concentration

$$\varepsilon_{2,3}(q) = \pm \sqrt{U^2 + q^4/\gamma_1^2} \quad q^2 = (vk)^2.$$

total in the bilayer

$$n = \frac{\gamma_1}{\pi \hbar^2 v^2} \sqrt{\mu^2 - U^2} = \frac{n_0 |U|}{\gamma_1} \sqrt{x^2 - 1}$$

$$x = \mu/U \quad n_0 = \gamma_1^2 / \pi \hbar^2 v^2 = 1.2 \times 10^{13} \text{ cm}^{-2}$$

separate In two layers

$$\begin{aligned} n_{1,2} &= \frac{\gamma_1}{2\pi \hbar^2} \int_U^\mu \sqrt{\frac{\varepsilon + U}{\varepsilon - U}} d\varepsilon \\ &= \frac{n_0 |U|}{2\gamma_1} [\sqrt{x^2 - 1} \pm \ln(x + \sqrt{x^2 - 1})]; \end{aligned}$$

Electron energy

$$V = \frac{2}{\pi \hbar^2 v^2} \int \varepsilon_{2,3}(q) q dq =$$
$$\pm \frac{n_0 U^2}{2\gamma_1} [x \sqrt{x^2 - 1} + \ln(x + \sqrt{x^2 - 1})]$$

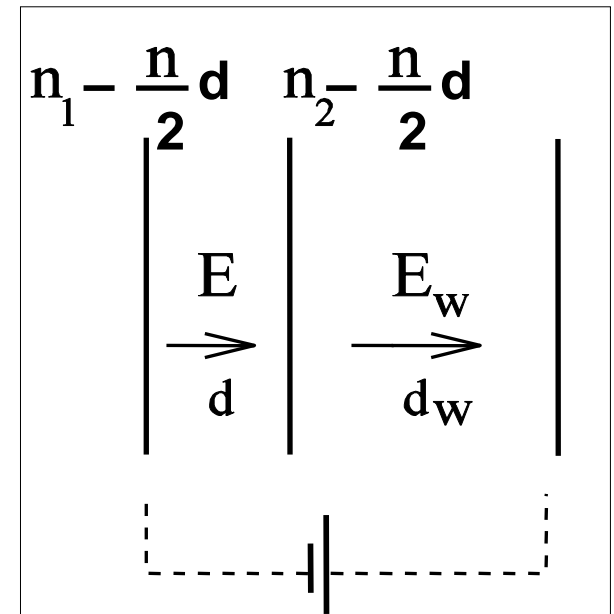
Field energy

$$V_f = \frac{1}{8\pi} (dE^2 + \epsilon_w d_w E_w^2)$$

$$4\pi e(n_1 - n_d/2) = E$$

Constraint

$$eV_g = -e^2 dE - e^2 d_w E_w$$



Result of minimization

$$\frac{\gamma_1 n_d}{U n_0} = \sqrt{x^2 - 1} \pm \left\{ f(x) + \frac{x f(x)}{\Lambda [x f(x) - \sqrt{x^2 - 1}]} \right\}$$

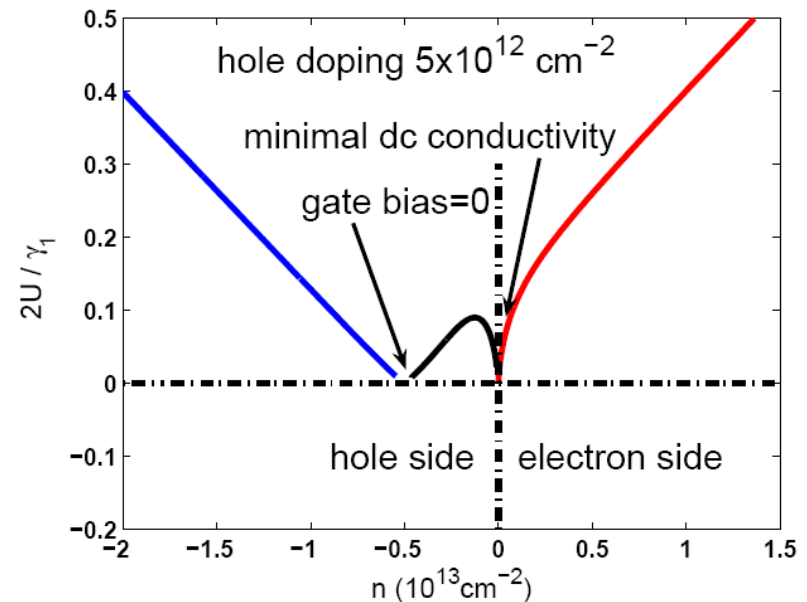
$$f(x) = \ln(x + \sqrt{x^2 - 1})$$

$$\Lambda = \frac{e^2 \gamma_1 d}{(\hbar v)^2} \quad x = \mu/U$$

$$x_0 = 6.2784$$

$$\frac{2U}{n} = \frac{2\gamma_1}{n_0 \sqrt{x_0^2 - 1}}$$

$$= 1.08 \times 10^{-11} \text{meV} \cdot \text{cm}^2$$



$$X = 6.28 \longrightarrow \infty \quad 1 \longrightarrow 6.28$$

Comparison to the previous result for

$$n_d = 0$$

$$\frac{2U}{n} = \frac{2\gamma_1}{n_0 \sqrt{x_0^2 - 1}} = 1.08 \times 10^{-11} \text{meV} \cdot \text{cm}^2$$

$$\frac{2U}{n} = \frac{e^2 d}{2\epsilon_0} \left[1 + 2\Lambda \frac{|n|}{n_0} + \Lambda \ln \frac{n_0}{|n|} \right]^{-1}$$

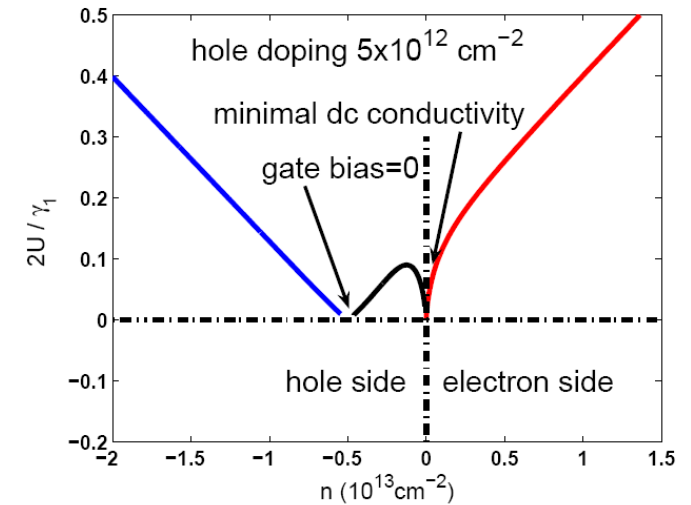
E. McCann, V.I. Fal'ko, Phys. Rev. Lett. **96**, 086805

E. McCann, Phys. Rev. B **74**, 161403(R) (2006).

Выводы

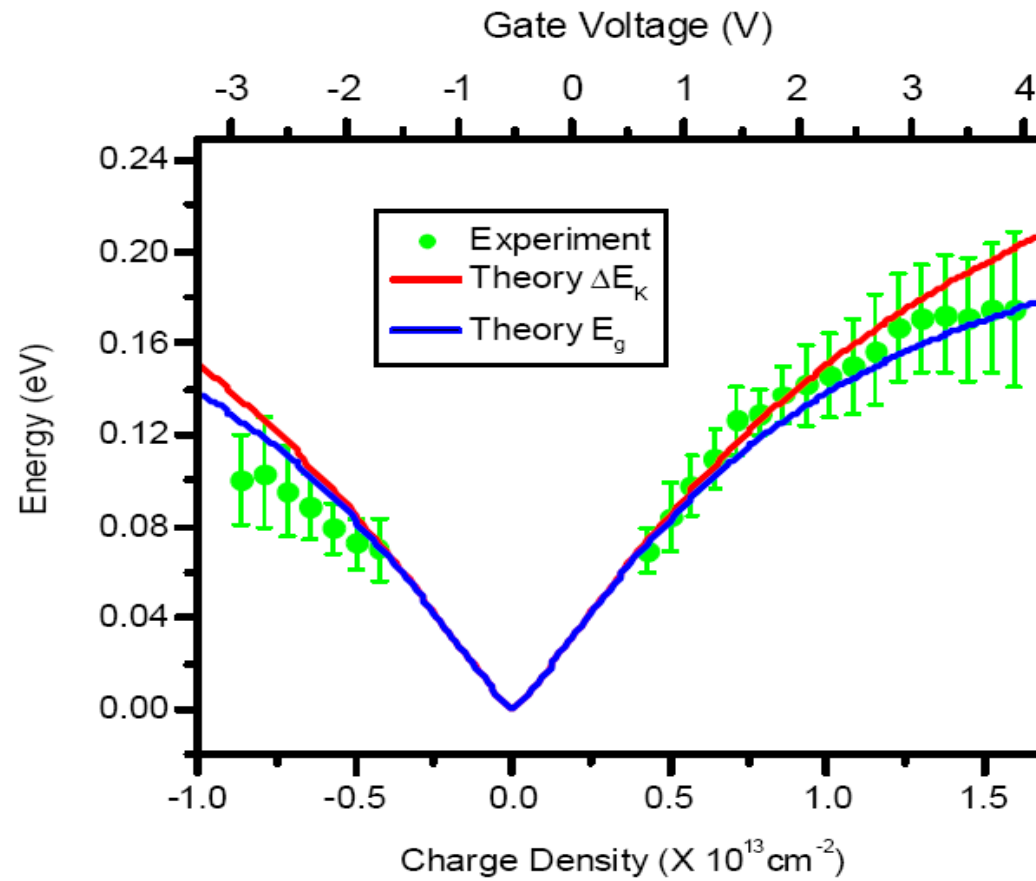
Щель как функция концентрации носителей

- 1) линейна в отсутствие допинга
- 2) в допированном двуслое является линейной при напряжении выше того, которое соответствует минимуму проводимости, и растет здесь корневым образом
- 3) при небольших концентрациях обнаруживает немонотонное поведение



Gap versus the carrier concentration

Mak et al (2009)



Bilayer optical transmittance

Li et al (2009)

