Spin Transfer at the Interface of Zigzag Graphene Hetrojunction

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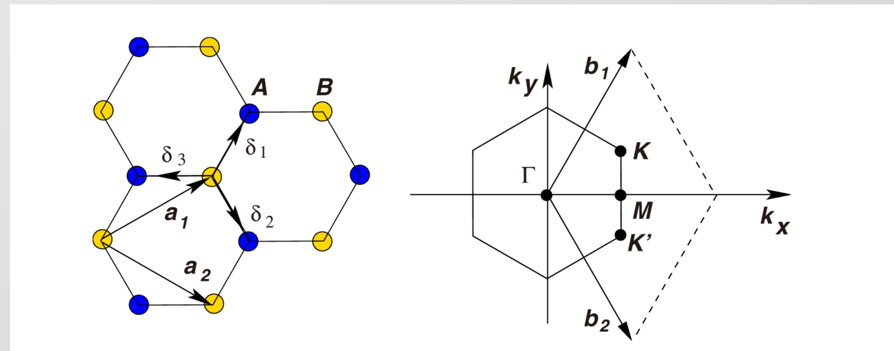
I. Abstract

Graphene is thought to be both an ideal material for spintronics due to weak spin-orbit interaction and also a prominent candidate for semiconductors in recent studies. Electrical spin-current injection and detection in graphene was recently demonstrated up to room temperature.

Here we study the spin transfer torque associated with the spin transport in the junction formed by graphene nano-ribbons. Our model is the zig-zag graphene nanoribbon(ZGNR) hetrojunction with the edge of one side reconstructed where the edge potential is expected to be modified. Why we should build up this scheme is that the atoms belong to one edge is inequivalent to another. This leads to the decoupling of the two valley in the low excited energy spectrum and may give birth to some interesting phenomenon when accompanied by the well-chosen edge potential.

II. Theoretical Background



The Hamiltonian of the honeycomb lattice approached by tight binding model is

$$\hat{H} = -t \sum_{<i,j>} \left(\boldsymbol{a}_i^\dagger \boldsymbol{b}_j + \boldsymbol{b}_j^\dagger \boldsymbol{a}_i\right) - t' \sum_{<<i,j>>} \left(\boldsymbol{a}_i^\dagger \boldsymbol{a}_j + \boldsymbol{a}_j^\dagger \boldsymbol{a}_i + \boldsymbol{b}_i^\dagger \boldsymbol{b}_j + \boldsymbol{b}_j^\dagger \boldsymbol{a}_i\right)$$

The effective Hamiltonian of this model shares exact the one of massless Dirac fermions. $H = v_F \boldsymbol{\sigma} \cdot \boldsymbol{p}$

For the sake of simplicity, since the decorating atoms on the edge lead to the deviation of the edge potential from the normal carbon atom, we confine this potential to be delta function with respect to the transverse position.

III. Energy Dispersion for Normal/Ferromagnetic ZGNR

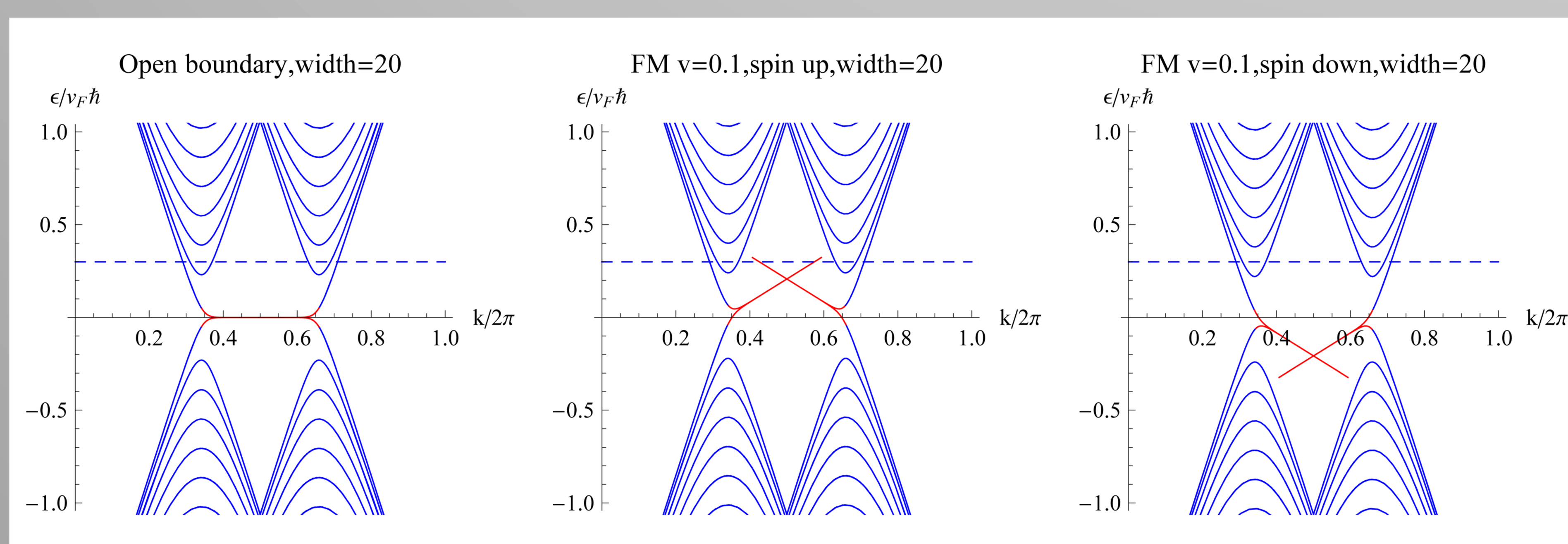
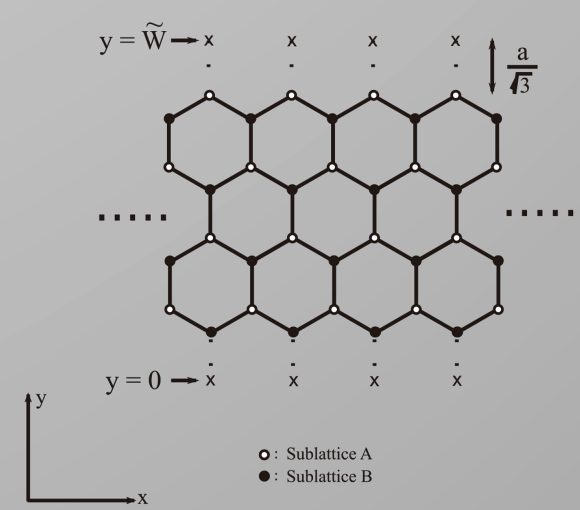


fig.2 Band structure for a graphene nanoribbon with 3 different zigzag boundary atom configuration and with 2 unit cell along transverse direction. The left panel corresponds to normal ZGNR while the others with v=0.2. Since the ZZ edge, the zero-energy regions in Brillouin Zone decouple completely into two inequivalent groups, which result in two valleys on the figure. The red line corresponds to edge states and the rest related with bulk states.

IV. Mode Matching and Linear Response approx.



The construction is stitched by two different ZGNR leads with one side normal and the other's edge potential altered. We now seek the mode-matching formalism. The open-boundary part is labeled as a subscript 1 while the other is subscript 2. Assume spin is along an arbitrary direction in spin space. Since the inter-valley wavefunction in the zigzag ribbon is decoupled, the intra-valley and inter-valley back-scatering should be taken in to consideration.

$$\Psi_1 = \Psi^{\text{in}} + \Psi^{\text{ref}} = \underbrace{e^{ik_p x}\psi_D^+(q_p, y)}_{\phi_p} \begin{pmatrix} \cos\frac{\theta}{2} e^{-i\frac{\phi}{2}} \\ \sin\frac{\theta}{2} e^{i\frac{\phi}{2}} \end{pmatrix} + \sum_{m,v} \underbrace{e^{-ik_{mv}x}\psi_v^-(q_{mv}, y)}_{\phi_{mv}^-} \begin{pmatrix} r_{mv}^\uparrow \cos\frac{\theta}{2} e^{-i\frac{\phi}{2}} \\ r_{mv}^\downarrow \sin\frac{\theta}{2} e^{i\frac{\phi}{2}} \end{pmatrix}$$

$$\Psi_2 = \sum_{n,v} \begin{pmatrix} t_{nv}^\uparrow e^{ik_{nv}^\uparrow x} \psi_v^{+\uparrow}(q_{nv}^\uparrow, y) \cos\frac{\theta}{2} e^{-i\frac{\phi}{2}} \\ t_{nv}^\downarrow e^{ik_{nv}^\downarrow x} \psi_v^{+\downarrow}(q_{nv}^\downarrow, y) \sin\frac{\theta}{2} e^{i\frac{\phi}{2}} \end{pmatrix}$$

match the wavefunction at x=0, $\Psi_1|_{x=0} = \Psi_2|_{x=0}$

$$\phi_{pD} \begin{pmatrix} \cos\frac{\theta}{2} e^{-i\frac{\phi}{2}} \\ \sin\frac{\theta}{2} e^{i\frac{\phi}{2}} \end{pmatrix} + \sum_{m,v} \phi_{mv}^- \begin{pmatrix} r_{mv}^\uparrow \cos\frac{\theta}{2} e^{-i\frac{\phi}{2}} \\ r_{mv}^\downarrow \sin\frac{\theta}{2} e^{i\frac{\phi}{2}} \end{pmatrix} = \sum_{n,v} \begin{pmatrix} t_{nv}^\uparrow \phi_{nv}'^{+\uparrow} \cos\frac{\theta}{2} e^{-i\frac{\phi}{2}} \\ t_{nv}^\downarrow \phi_{nv}'^{+\downarrow} \sin\frac{\theta}{2} e^{i\frac{\phi}{2}} \end{pmatrix}$$

Each component of the above equation should satisfy(suppose Ψ^{in} is at valley D)

$$\phi_p + \sum_{m,v} r_{mv}^\sigma \phi_{mv}^- = \sum_{n,v} t_{nv}^\sigma \phi_{nv}^{+\sigma} \Rightarrow \sum_{m,v} \delta_{mp}\delta_{vD}\phi_{mv}^+ + \sum_{m,v} r_{mv}^\sigma \phi_{mv}^- = \sum_{n,v} t_{nv}^\sigma \phi_{nv}'^{+\sigma}$$

Due to the conservation of Chirality in graphene, intra-valley backscattering is suppressed while inter-valley backscattering can take place. In this sense, the backscattering wave function concerns both valley.

V. Summary and References

Numerical calculation has been performed but insufficient result figured out. By far we have known the electron transport in graphene is nearly ballistic transport at higher energy for both spin channel. But at lower energy, the construction filter out most spin up electrons(spin direction perpendicular to ZGNR plane), which makes the hetrojunction a potential material for spintronics. Due to spin filtering mechanism, an additional torque exerted on the magnetization. More properties of the construction is being hunted.

1. Castro Neto, et al. Rev of Mod Phys 81(1),109,2009
2. Yokoyama, Phys. Rev. B 77, 073413 (2008)
3. M. D. Stiles, Phys. Rev. B 66, 014407 (2002)