Screening in chiral multilayer graphene

Hongki Min

hmin@snu.ac.kr

Department of Physics and Astronomy, Seoul National University, Korea

In collaboration with E. H. Hwang and S. Das Sarma

Min, Hwang and Das Sarma, arXiv:1202.2132 (2012)



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Motivation

Polarizability and dielectric function

$$\chi_0(q,\omega) =$$

$$\varepsilon^{\text{RPA}}(q,\omega) = 1 - \upsilon_{\text{C}}(q) \chi_0(q,\omega)$$

⇒ Transport properties,
Collective modes,
Ordered states,
Correlation energies,

What is the polarizability of multilayer graphene systems?



Electronic structure of multilayer graphene

Three distinct stacking arrangements, labeled A,B,C



Electronic structure of multilayer graphene

Stacking sequence and energy band structure

Min and MacDonald, Phys. Rev. B 77, 155416 (2008)



Electronic structure strongly depends on the stacking sequences. Low-energy band structure is described by a set of chiral systems. High-energy band structure follows that of monolayer graphene.

Low energy effective model

Chiral 2D system (C2DES) with a chirality J

$$H_{J} = t_{\perp} \begin{pmatrix} 0 & \left(\frac{\hbar v k_{\perp}}{t_{\perp}}\right)^{J} \\ \left(\frac{\hbar v k_{\perp}}{t_{\perp}}\right)^{J} & 0 \end{pmatrix}$$

$$k_{\pm} = k_x \pm i k_y$$

 t_{\perp} : interlayer coupling

— Multilayer graphene is described by a set of C2DESs

- Energy spectrum
$$\varepsilon_{\mathbf{k},s} = st_{\perp} \left(\frac{\hbar v k}{t_{\perp}}\right)^{J} \quad (s = \pm 1)$$



Theory

Static bare polarizability

$$\chi_0(q) = g \sum_{s,s'} \int \frac{d^2k}{(2\pi)^2} \frac{f_{\mathbf{k},s} - f_{\mathbf{k}+\mathbf{q},s'}}{\varepsilon_{\mathbf{k},s} - \varepsilon_{\mathbf{k}+\mathbf{q},s'} + i0^+} F_{ss'}(\mathbf{k}, \mathbf{k}+\mathbf{q})$$

 f_k : Fermi distribution function for kg: spin/valley degeneracy factor s : band index

$$F_{ss'}(\mathbf{k},\mathbf{k'}) = \left| \left\langle \Psi_{s}(\mathbf{k}) \right| \Psi_{s'}(\mathbf{k'}) \right\rangle \right|^{2}$$

tan ¢

Ex) C2DES :
$$F_{ss'}(\mathbf{k}, \mathbf{k}') = \frac{1}{2} [1 + ss' \cos J(\phi_{\mathbf{k}} - \phi_{\mathbf{k}'})]$$

 $\xrightarrow{s = s', \phi_{\mathbf{k}} - \phi_{\mathbf{k}'} = \pm \pi} 0$ for odd J, 1 for even J

$$\Rightarrow \text{Suppressed } 2k_{\text{F}} \text{ backscattering for odd } J$$

Enhanced $2k_{\text{F}}$ backscattering for even J

Static bare polarizability: chirality dependence

Chiral 2D electron system (C2DES) with a chirality J



No cusp structures at $q=2k_F$ for odd J due to suppressed backscattering

Static bare polarizability: density dependence

Bilayer graphene (*J*=2 chiral gas at low densities)



At low densities, polarization follows the trend of *J*=2 C2DES. At large densities, polarization follows monolayer trend.

Static bare polarizability: density dependence

ABC trilayer graphene (*J*=3 chiral gas at low densities)



At low densities, polarization follows the trend of *J*=3 C2DES. At large densities, polarization follows monolayer trend.

Static bare polarizability: density dependence

ABA trilayer graphene (J=1,2 chiral gases at low densities)



Static bare polarizability: onsite U dependence

Monolayer graphene with $n=10^{12}$ cm⁻²



For *U*=0, backscattering is suppressed for monolayer graphene. As *U* increases, cusp structure is developed.

Conclusion

- At low densities,
 - Spectrum is described by a set of C2DESs
 - $-\chi_0(q)/N_{\rm F}$ Polarizability behaves as that 0.5 of C2DES with the largest chirality
 - At high densities,
 - Spectrum looks like a collection of monolayers
 - Polarizability follows that of monolayer graphene
- Onsite energy difference could enhance or suppress
 - Backscattering depending on the chiral nature
 - Cusp at $2k_{\rm F}$

Min, Hwang and Das Sarma, arXiv:1202.2132 (2012)

ABA

1.5 | (J=1,2)

n=10

 $q/k_{\rm E}$

<u>/=2</u>

 $n=0.1 \times 10^{12} \,\mathrm{cm}^{-2}$

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