Supplementary Information: Novel mid-infrared plasmonic effects in bilayer graphene

Tony Low[1], Francisco Guinea[2], Hugen Yan[1], Fengnian Xia[1,3], and Phaedon Avouris[1]
[1] *IBM T.J. Watson Research Center, 1101 Kitchawan Rd, Yorktown Heights, NY 10598, USA*
[2] *Instituto de Ciencia de Materiales de Madrid. CSIC. Sor Juana Inés de la Cruz 3. 28049 Madrid, Spain*
[3] *Yale University, 15 Prospect Street, New Haven, CT 06511, USA*
(Dated: September 10, 2013)

I. ELECTRONIC BANDS AND WAVEFUNCTIONS IN BILAYER GRAPHENE

We present the solutions for the non-interacting ground state electronic bands and wavefunctions used in the main manuscript. We consider a bilayer graphene arranged in the Bernal stacking order with basis atoms A_1, B_1 and A_2, B_2 in the top and bottom layers respectively. The intralayer coupling is γ_0 and the interlayer coupling between A_2 and B_1 is γ_1. The non-interacting electronic Hamiltonian in the (A_1, B_1, A_2, B_2) basis representation in the vicinity of $\mathbf{K}$ valley reads[1],

$$\mathcal{H}_0 = \sum_{\mathbf{k}} \hat{a}^\dagger_{\mathbf{k}} H_{\mathbf{k}} \hat{a}_{\mathbf{k}} \tag{1}$$

with

$$H_{\mathbf{k}} = \begin{bmatrix} \Delta/2 & v_F\pi_- & 0 & 0 \\ v_F\pi_+ & \Delta/2 & \gamma_1 & 0 \\ 0 & \gamma_1 & -\Delta/2 & v_F\pi_- \\ 0 & 0 & v_F\pi_+ & -\Delta/2 \end{bmatrix} \tag{2}$$

where $\pi_\pm = \hbar(k_x \pm k_y)$, $v_F = \frac{3}{2}L\gamma_0/\hbar$, L is the carbon-carbon bondlength and Δ is the on-site energy difference between the two layers. The electronic bands and wavefunctions are obtained by diagonalizing $H_{\mathbf{k}}$. The electronic bands are denoted by $\xi_n(\mathbf{k})$, with $n = 1, 2, 3, 4$ in ascending energy order given by,

$$\xi_n(\mathbf{k}) = \pm\frac{1}{2}\sqrt{\pm 2\Omega + \Delta^2 + 2\gamma_1^2 + 4v_F^2\pi_+\pi_-} \tag{3}$$

where $\Omega \equiv \sqrt{4\Delta^2 v_F^2\pi_+\pi_- + 4v_F^2\gamma_1^2\pi_+\pi_- + \gamma_1^4}$ and the signs are chosen as $-+$, $--$, $+-$ and $++$ for $n = 1, 2, 3, 4$ respectively. Their 4-component wavefunctions denoted by $|\Phi_n(\mathbf{k})\rangle$ are given by,

$$\frac{1}{N}\begin{bmatrix} 1 \\ \frac{1}{2v_F\pi_-}(2\xi_n - \Delta) \\ \frac{1}{2v_F\gamma_1\pi_-}(-2\Delta\xi_n + \Delta^2 + \gamma_1^2 \pm \Omega) \\ \frac{1}{8v_F^2\gamma_1\pi_-^2}(-4\Delta v_F^2\pi_-\pi_+ - 8\xi_n\pi_+\pi_- v_F^2 - 8\xi_n\gamma_1^2 + \Delta^3 + 4\gamma_1^2\Delta + 8\xi_n^3 - 4\xi_n^2\Delta - 2\xi_n\Delta^2) \end{bmatrix} \tag{4}$$

where N is the normalization constant, and the $\pm$ sign are choosen as $+$, $-$, $-$ and $+$ for $n = 1, 2, 3, 4$ respectively.

[1] E. McCann, "Asymmetry gap in the electronic band structure of bilayer graphene," *Phys. Rev. B*, vol. 74, p. 161403R, Sep 2006.