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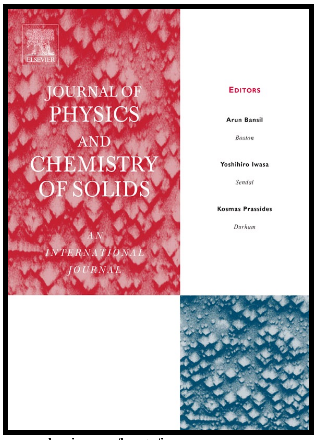

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Effect of asymmetric Fermi velocity on trigonally warped spectrum of bilayer graphene

ACCEPTED MANUSCRIPT

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We derive an effective Hamiltonian at low energies for bilayer graphene when Fermi velocity manufactured on each layer is different of the velocity measured in pristine graphene. Based on the effective Hamiltonian, we investigate the influence of Fermi velocity asymmetry on the band structure of trigonally warped bilayer graphene in the presence of interlayer applied bias. In this case, the Fermi line at low energies is still preserved its threefold rotational symmetry appearing as the three pockets. Furthermore, the interlayer asymmetry in Fermi velocities leads to an indirect band gap which its value is tunable by the velocity ratio of the top to bottom layer. It is also found that one of the origins for emerging the electron-hole asymmetry in the band structure, is the velocity asymmetry which is large around the trigonal pockets.

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I. INTRODUCTION

One of the great interest to study bilayer graphene comes back to its potential application in nano-electronics, thanks to opening a tunable gap by means of an applied electric field[1–7]. Low energy band structure of bilayer graphene undergoes an asymmetric shaped named as trigonal warping (TrW) for energies lower than the Lifshitz energy[1,7–11]. TrW is originated from the skew interlayer hopping integral between $A_d - B_u$ atoms in a Bernal stacking bilayer graphene. Although TrW is effective for only very low energies (of the order of 1 meV) in the dispersion, it has a significant impact on the minimal conductivity such that conductivity increases to six times as large as that for single layer graphene[11,12]. In the absence of inter-valley scattering, TrW causes to suppress weak localization[13]. Moreover, TrW affects magnetotransport and scaling properties of a bilayer graphene in the Corbino geometry[14]. In a junction containing of two trigonally warped bilayer graphene in which two biases are applied with opposite polarities, two topological confined states emerge inside the gap[15].

The electronic properties of graphene can be modified by many scattering factors such as structural deformation[16], doping[17], dielectric screening[18,19] and electron-electron interaction[20–22] which give rise to a change in the Fermi velocity of charge carriers in each graphene layer. Some of structural factors can be enumerated as strain[16], modification in curvatures of graphene sheets[23] or generating graphene superlattices by means of a periodic potentials[24–26], lattice incommensurability with the substrate[27], a twist in bilayer graphene[28] or folded graphene[29]. So a modification in Fermi velocity of carriers induced by strain and curvatures such as nanoscale ripples or envirnmental factors is an inevitable event during an experiment especially for a bilayer graphene grown on a substrate in which layer symmetry breaks[30].

A change in Fermi velocity of Dirac fermions in monolayer graphene only leads to a renormalized Dirac cones[31] while an interlayer velocity asymmetry applied on bilayer graphene induces an indirect band gap which is controllable by the velocity ratio of the upper to lower layers[32]. Let us mention that our last study on band structure modification induced by velocity asymmetry was focused on high energy excitations with 4×4 full Hamiltonian. However, the influence of velocity asymmetry on TrW of bilayer graphene at low energies around Lifshitz energy has not been investigated. Regarding to the importance of TrW, we derive an effective 2×2 Hamiltonian which describes low energy massive Dirac fermions in a bilayer graphene when Fermi velocity of charge carriers itinerant in each layer are different. By analysing term by term of the Hamiltonian, the influence of velocity asymmetry on the TrW deformation is investigated while an interlayer electric field is present. Emerging an indirect band gap when a small vertical bias is applied, can have significant effect on conductance through bilayer graphene. Moreover, it is proved that such interlayer asymmetry in Fermi velocity is able to generate the electron-hole (e-h) asymmetry in the spectrum.

This paper is organized as follows. After the introduction, in Sec.II, the effective Hamiltonian is derived by projecting the full Hamiltonian on the non-dimer sites.

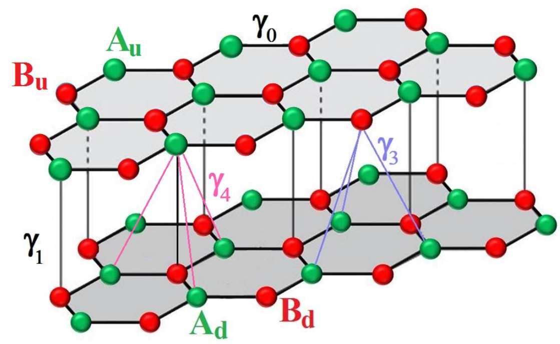

FIG. 1: Schematic view of bilayer graphene with Bernal stacking. Sub-lattices for the bottom layer (A_d, B_d) and for the topper layer (A_u, B_u) are coupled to each other with two skew interlayer couplings, γ_3 and γ_4.

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