Ballistic electron transport in the magnetic Bloch states of graphene superlattices

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Abstract

Van der Waals heterostructures sparked a lot of interest in recent years, as they open new pathways to tweak material properties by stacking 2D layers of different crystals. Controlling the crystallographic alignment between different layers recently lead to striking developments, such as superconductivity, ferromagnetism or new collective modes. One of the most popular heterostructure so far is comprised of graphene encapsulated between two hexagonal boron nitride (hBN) flakes, one of which is crystallographically aligned with the graphene layer [1]. Not only does this improve the electronic properties of graphene, but the Moiré superlattice created reduces the size of the Brillouin zone and creates second-generation Dirac fermions [2, 3]. In the presence of a magnetic field, this enables the observation of the Hofstadter's butterfly, via the formation of third-generation Dirac fermions. Notably in graphene superlattices, the recurrence of delocalised Bloch states whenever the magnetic length becomes commensurate with the superlattice periodicity results in conductivity oscillations [4,5]. In details, the electronic wave function extension of electrons confined in the superlattice potential meets the magnetic length, allowing the electrons to recover delocalised wave functions and behave as magnetic Bloch states (MBS). There, electrons propagate with straight trajectories in a vanishing effective field ($B_{eff} = 0$). The mini-bands formed at those MBS are new metallic states arising at magnetic fluxes on the sequence $\phi = \phi_0 \cdot p/q$ (where p and q are integers and ϕ_0 is the flux quantum).
We present the magneto-transport properties of aligned graphene-hBN heterostructures, with a focus on MBS mini-bands. We show that those metallic states at high magnetic fields have exceptionally high mobility and support long-range ballistic transport. Further, the high quality of our devices enabled us to measure the degeneracy of those states and attest for the complete lifting of the degeneracy at low temperatures, consistently with recent suggestions [6,7]. We finally report a bending of the Landau fans under high magnetic fields close to the superlattice gap, that we propose is due to the formation of flat bands in the MBS mini-band spectrum. Overall, our statement paves the way to a better understanding of the fundamental Bloch states appearing with the superlattice-induced periodicity and may arouse interest for studies of many-body effects in this material.

References

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