Pressure-enhanced robustness of helical edge state in ABA Tri-layer Graphene

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Multi-layer graphene systems are promising platforms to study interesting physical phenomena, including unique quantum hall physics, spontaneous symmetry breaking, and topological properties. Here, by applying hydrostatic pressure on the tri-layer ABA graphene, the phase diagram at the charge neutrality point undergoes a significant change, indicating a complicated interplay among different energy scales. Also, quantum parity hall state, a kind of helical edge state protected by mirror symmetry, emerges after pressure. The measured Landau Fan diagram illustrates the modification of the band structure by pressure, which can be used to explain the observed phenomenon.

INTRODUCTION

Regarding multilayer graphene systems, their rich physical properties make them widely regarded as a platform for studying unconventional properties of two-dimensional electron systems. Up to now, many intriguing physical phenomena has been found in multilayer graphene systems, ranging from single-particle to many-body physics, such as the Lifshitz transition of Fermi surface topology [1, 2], Landau level crossing in a single particle scenario [3] [4, 5], quantum hall ferromagnetism at high perpendicular magnetic field [6, 7, 8, 9], and various symmetry broken states near charge neutrality and low magnetic field [8,9].

Among them, ABA tri-layer graphene has attracted widespread attention due to its unique band structure at low energy regime. As a highly tunable platform, it provides an excellent opportunity to study its single-particle band structure and many-body phenomenon. In previous studies, researchers have typically analyzed its electronic properties by manipulating carrier density, displacement field, and magnetic field and have achieved significant results in this system. Notably, because the low-energy band structure of multilayer graphene is highly sensitive to the interlayer hopping strength, applying pressure to reduce the interlayer distance and further study its properties has become a highly promising research approach. Therefore, pressure can be viewed as a powerful tool to investigate the details of electronic structure deeply.

In recent years, condensed matter physics has witnessed a growing interest in exploring the topologically non-trivial edge states in materials. Among them, the helical edge state is a special boundary state featuring non-dissipative channels with opposite motion directions. Helical conductors have been proposed to realize Majorana statistics for quantum computation[12, 13, 14, 15]. There are multiple ways to achieve helical edge states, including topologically non-trivial band structures protected by time-reversal symmetry, such as those found in QSHE systems [16, 17, 18]. In addition, in systems where the conduction band is energetically below the valence band, the introduction of a magnetic field or displacement field can lead to the intersection of “hole-like” states with “electron-like” states at the system’s boundary, thereby creating a pair of spin-degenerate helical edge states. The advent of multilayer graphene has provided physicists with a versatile platform for exploring different types of helical edge states because of the unique band structure near the charge neutrality point (CNP) and the high achievable mobility of this material. A wealth of experimental evidence has confirmed the existence of helical edge states in various graphene configurations, ranging from monolayer to tetralayer graphene [1, 11, 19, 21]. The exploration of helical edge states and other topological properties has led to exciting advances in condensed matter physics for their potential applications in areas such as quantum information processing and spintronics. Tri-layer ABA graphene is an interesting material to study quantum hall physics and symmetry-broken states since the low-energy band structure of tri-layer ABA graphene consists of a monolayer-like branch and a bilayer-like branch in the absence of displacement field, as shown in Figure 1(b). Both branches are protected by mirror symmetry and have odd and even parity. Although decoupled from each other, the two bands have an energy overlap between the monolayer-like valence band and the bilayer-like conduction band. However, when a displacement field is applied, they mix due to mirror symmetry breaking. The unique band structures and symmetries lead to various novel phenomena, which make the tri-layer ABA graphene interesting.

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