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Valley Hall Effects in Graphene/hBN Superlattices

Nowadays, as the “Internet of Things” has evolved in international society, the demand of electronic devices drastically increases and energy consumption becomes a serious issue. To solve this problem, the concept to use valley degree of freedom as an information carrier has been proposed as a new type of electronics. This concept called “Valleytronics” [1], used in the same analogy with Spintronics, is studied for low power consumption applications and for deepening the understanding of topological quantum properties in condensed matter physics. Among some materials for Valleytronics, graphene possesses the potential to provide an ideal platform. Graphene has two valley degrees of freedom called K and K’ points in the momentum space due to the honeycomb lattice structure. Furthermore, the development of technology to fabricate two-dimensional (2D) van-der-Waals heterostructure allow to realize high-quality graphene devices [2]. In particular, the stacking of graphene and hexagonal boron nitride (hBN) with precise angle alignment against crystalline orientation (<1°) gives rise to superlattice potential, leading to breaking inversion symmetry in graphene. Then, non-zero Berry curvature emerges at each valley with opposite sign, which acts as magnetic field in the momentum space. In consequence, the electrons obtain anomalous velocity with opposite direction for each valley. This is called valley Hall effect, can be used to electrically polarize the valley degree of freedom [3].

Even though the investigation of the valley Hall effect in detail is crucial for the development of Valleytronics, the observation of the valley Hall effect requires a high-quality device. However, such device is difficult to be realized because of difficulty and complexity of the fabrication process.

Here we show the development of the device fabrication process and discuss the device fabrication process and the valley Hall effect in the single layer graphene/hBN superlattice and the bilayer graphene/hBN superlattice devices [4,5]. For the device fabrication process, we use the polymer stamp made of dimethylpolysiloxane and polypropylene carbonate, which allows to control the pick-up and the drop-down by changing the temperature. By controlling the speed of the approaching 2D materials and the angle between the stamp and the substrate, we can avoid the formation of bubbles at the interface as less as possible. This is important to fabricate high-quality samples. In single layer and bilayer graphene devices, the fractal spectrum in the local resistance mapping plot of gate voltage and perpendicular magnetic field was observed, inferring the superlattice structure. Moreover, we observed the non-local resistance by using the Hall-bar geometry as shown in Figure 1 [4], which can be attributed to the valley Hall effect and its inverse effect [6].

References

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Figures

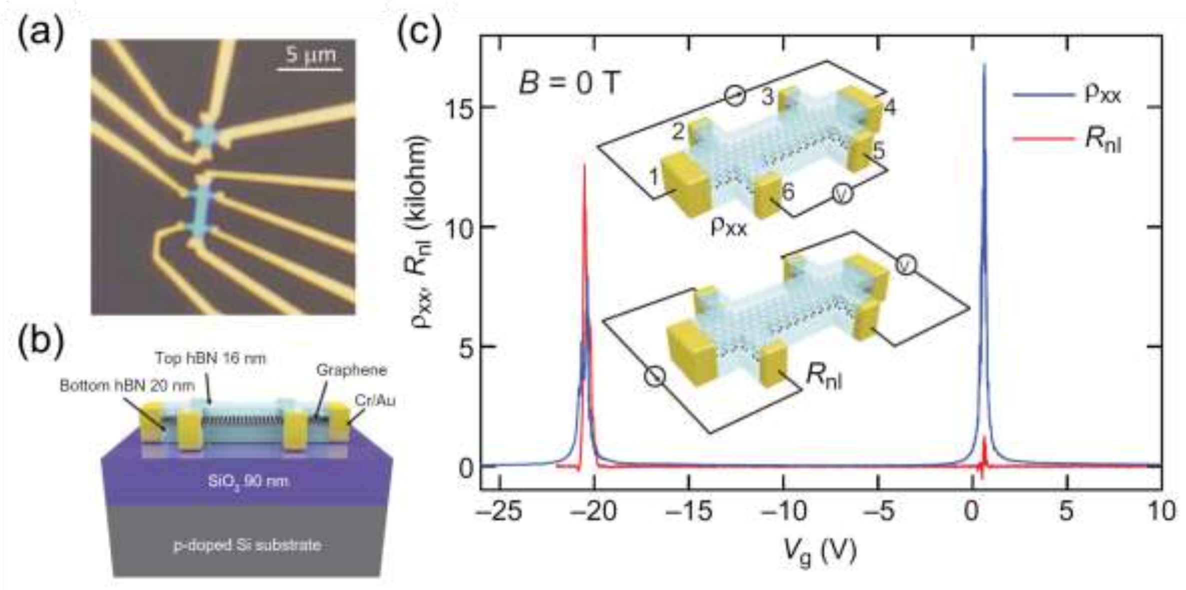

Figure 1: Valley Hall effect in the graphene/hBN superlattice device [4]. (a) Optical image of the device. (b) Schematic image of the device. (c) Longitudinal resistivity (ρ_{xx}) and non-local resistance (R_{nl}) vs. gate voltage (V_g) characteristics of the device at 1.5 K, zero magnetic field (B). Insets show the configuration for local (upper) and non-local (lower) measurements. Around V_g ~ -20 V (secondary Dirac point), the high non-local resistance is observed due to the valley Hall effect and the inverse effect.