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Valley Hall Effect in Ungated Bilayer Graphene

Introduction of Berry's phase and related effects has led to the study of yet another degree of freedom in electrons i.e. valley degree of freedom and a brand new branch of research, Valleytronics [1]. This degree of freedom gives scope for a novel information carrier for electronic devices, apart from the charge and spin degree of freedom [2,3]. Berry phase has given rise to various physical properties such as Berry curvature and orbital magnetic moment. Berry curvature, which can be described as a pseudo-magnetic field in the reciprocal space drives the carriers to the opposite edges of the materials according to the direction of the curvature in the presence of an in-plane electric field. This phenomenon is called valley Hall effect.

Valley Hall effect is widely studied in two-dimensional materials including bilayer graphene [4,5]. However, these studies used a complicated device structure consisting of bilayer graphene sandwiched between hBN (hexagonal boron nitride) layers. In addition, as they could not observe any valley Hall effect in unbiased bilayer graphene, an electric field had to be applied between the top and bottom gates to break the symmetry between the layers and induce valley Hall effect. However, in the current study, we observed the valley Hall effect in unbiased bilayer graphene exfoliated on Si/SiO_2 substrate. Fig. 1a shows the valley Hall effect detected using non-local electrical measurement in unbiased bilayer graphene. In the non-local measurement setup, the current is sent across the terminals at one end of the device and the voltage is detected at the other end. The observation of the valley Hall effect in unbiased bilayer graphene is attributed to the emergence of Berry curvature (which is the driving force that pushes the electrons to the other end of the device) as a result of the layer asymmetry in bilayer graphene. The layer asymmetry comes from the proximity effect where the Si/SiO_2 substrate induces different potentials between the two layers of the bilayer graphene which in turn breaks the layer symmetry in the system. In order to confirm that the non-local resistance is indeed from the valley Hall effect induced by the Berry curvature, we calculated the Ohmic contribution to the non-local resistance using the van der Pauw formula given as,

$$R_{Ohmic} = R_L \left(\frac{W}{\pi L}\right) e^{-\frac{\pi L}{W}} \quad (1)$$

where R_L is the local resistance and W and L are the width and length of the bilayer Graphene respectively. The Ohmic contribution comes from the diffusion of the charge carriers from one end of the device to the other end. The calculated Ohmic contribution (Fig. 1b) is more than two orders of magnitude less than the measured non-local resistance. Thus it can be affirmed that the measured non-local resistance is a signature of the valley Hall effect.

These results are especially important because none of the experimental studies conducted so far have observed substrate induced valley Hall effect in unbiased bilayer graphene. Also, unlike earlier studies [4,5], our scheme does not employ any complicated fabrication process such as encapsulation of bilayer graphene with hBN layers or the introduction of a top gate. We have also carried out the temperature dependence of the non-local resistance.

References

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Figures

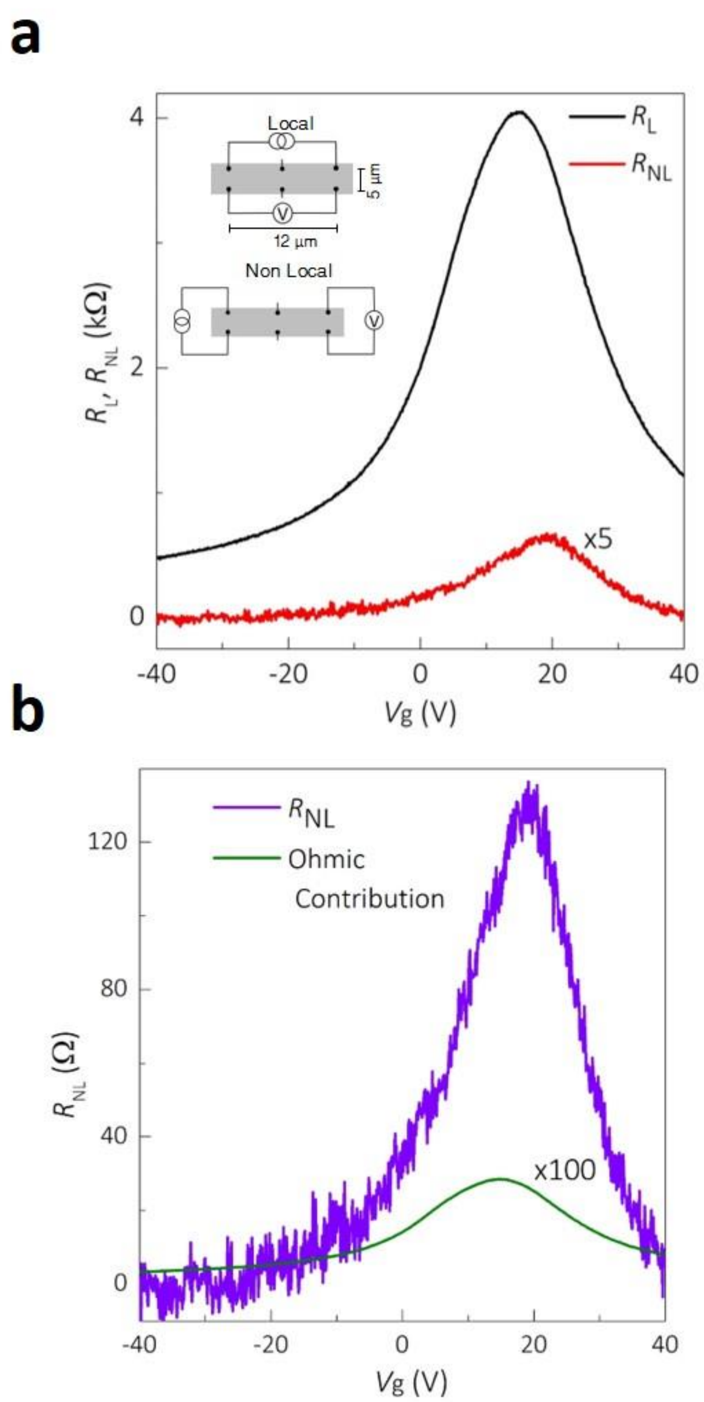

Figure 1: (a) Local and non-local resistance measurement of ungated bilayer graphene as a function of gate voltage. (b) Ohmic contribution to the non-local resistance calculated using the van der Pauw formula.