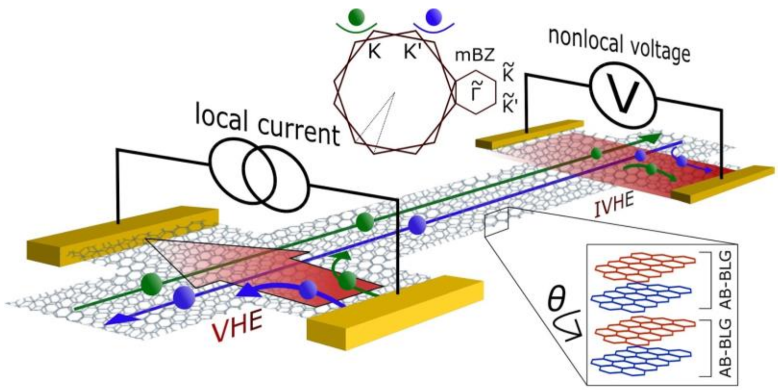
A new twisted graphene system hosts chargeless valley current

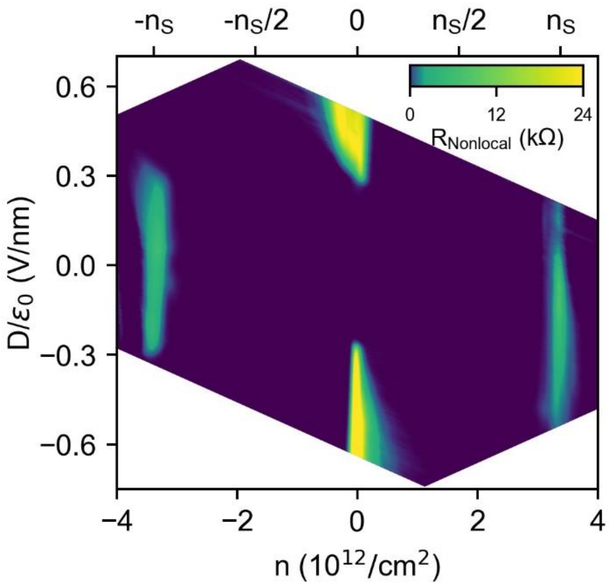
In a recent study, the Nanoelectronics lab in TIFR has found a novel route to generate and detect a chargeless valley current. Valleys represent energetically degenerate but structurally distinguishable points in the band structure of a material. Whenever electrons associated with a particular valley quantum number flow, it gives rise to a dissipationless valley current where the net electronic charge transferred is zero--this can potentially be used as robust channels of information carriers. But engineering systems that can carry valley current has remained a big challenge, and very few systems thus far have been shown to host such a current. The team was not only able to generate and tune this current in a new engineered 2D system but also showed that the underlying bands that host these currents are of topological nature. The work combines valley current with topology in 2D materials and hence is an important milestone in understanding the origin of a quantum phase of matter called quantum anomalous Hall insulator in which current carrying dissipationless quantum modes are topologically protected from backscattering. This research was published in the 03 November 2020 online issue of Nature Communications.



Caption: *Schematic of the fabricated twisted double bilayer graphene device, along with the valley current flowing through the bulk.*

If let's say, we paint five electrons each with green and blue, and push green electrons to the right and the blue ones to the left, this drives a current of green and blue electrons even though the net transfer of electron number is zero. The valleys do precisely this job of painting, i.e., labelling the electrons with a particular quantum number. Just like electrons have a spin degree of freedom, when electrons move in the hexagonal lattice like that of graphene, they acquire this additional valley degree of freedom. The push to these valley-painted electrons is provided by Berry curvature, a band property of purely quantum mechanical origin. The team, led by Prof. Mandar M. Deshmukh, engineered a new Berry curvature rich graphene-based system, where they sliced bilayer graphene into two pieces and stacked the two pieces on top of each other with a small twist angle. The device is named twisted double bilayer graphene, aka TDBG. This new field of stacking 2D materials with small twist angles is termed as "twistronics", and has become a recent craze in the past two years due to its ability to engineer flat non-dispersive bands that host a plethora of correlated states. Unfortunately, fabricating twisted devices is non-trivial. The group developed a technique of slicing thin 2D flakes in the lab, which was a major breakthrough to fabricate these devices.

“The two fields--valleytronics and twistronics--were thus far seen to be disconnected fields. Our work confirms a fruitful merging of these two fields into one: *valley-twistronics*”, said Subhajit Sinha, a joint co-author together with Pratap Chandra Adak. “Twisted double bilayer graphene seems to host a plethora of novel quantum states--our findings may just be the tip of an iceberg yet to be explored” -- Subhajit added. Pratap pointed out, “While our work may open up a new avenue in valley-twistronics from an application point of view, this has importance in understanding fundamental physics of twisted systems. After the discovery of superconductivity in twisted bilayer graphene, a cousin of twisted double bilayer graphene, these systems are being explored aggressively. But all the mysteries are still unresolved. Our experiment cast some light.”



Caption: *A colour-scale plot of resistance with doping in x-axis and electric field in y-axis. Peaks in the resistance (yellow and green colour) are signatures of valley current.*

The group collaborated with Prof J. Jung and B. L. Chittari from the University of Seoul to shed new light on understanding the origin of this valley current. Theoretical calculations revealed that even though the bands are flat, it can have local pockets where large Berry curvature resides and pushes the valley electrons in opposite directions to drive the valley current. Thanks to TDBG’s electric field tunability, the valley current in these new twisted 2D heterostructures can potentially be further used to controllably tune robust channels of information carriers in next-gen electronic devices.

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