Internship proposal

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Mechanical friction between perfectly flat 2D materials

Interfacial adhesion and friction are of special interest for the development of microelectromechanical systems. The frictional force between two perfectly flat materials is highly dependent on the orientation between the layers. The clearest example of this is superlubricity, a phenomenon proposed theoretically in [Hirano *et al.,* PRB 41, 11837 (1990)], which consists in an ultralow friction state between graphite layers in incommensurate states. The lattice mismatch created by the incommensurate lattices results in the cancellation of one of the channels of energy dissipation, preventing the collective stick-slip motion of atoms in contact and as a consequence the kinetic friction force is vanishingly small. Other dissipative processes, such as electronic and phononic friction, persist and therefore the net frictional force will not be zero. Nevertheless, the reduction of the friction is expected to be of orders of magnitude. This phenomenon has been measured experimentally [Dienwiebel *et al.*, PRL 92, 126101 (2004), Koren *et al.*, Science 348, 6235 (2015)] showing a frictional force between layers within the sensitivity of the instrument (or virtually zero) and a high angular dependence of the friction force with the orientation between layers. This dependence showed an increase of orders of magnitude in the friction close to perfect alignment of the layers, with the expected 60° periodicity characteristic of the honeycomb lattice structure. Interestingly, these highly sensitive friction measurements have not shown any indication of other commensurate states, probably because the remaining friction forces (*e.g.* phononic and electronic friction) are much larger than the friction generated by these commensurate states, or because the resolution of the instrument was not good enough.

Superlubricity has not been measured in other material, nor in combination of different materials. The question of the existence of superlubricity between two layers with different lattice constants remains to be investigated. We propose to combine recent developments in the fabrication of van der Waals heterostructure with advance atomic force microscope techniques to investigate the frictional forces between perfectly flat 2D materials with different lattice constants. This thesis project will focus on the understanding of: the existence of superlubricity in incommensurate materials, scaling of the friction between perfectly flat surfaces (*e.g.,* area versus edge scaling), role of phononic and electronic friction and interlayer spacing effects.

Methods and techniques: Frictional forces, micro and nano fabrication, 2D materials