Twistable electronics with dynamically rotatable heterostructures

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In situ band structure manipulation of 2D materials offers unique opportunities toward understanding of multiple physical phenomena and the design of novel opto-electronic devices. A simple, yet effective, way to modify the band structure of these materials is by controlling the relative orientation between the layers in van der Waals heterostructures. The clearest example of this effect is graphene on hexagonal boron nitride (BN), in which the layer orientation determines the wavelength of the Moiré superlattice, which in turn modifies the native band structure of graphene opening an energy gap and generating minigaps at higher energies. However, current techniques are limited to fabrication of samples with fixed interlayer angles. Studies of angular dependence are therefore limited to static properties, and require multiple samples, which imposes experimental challenges and introduces uncertainty due to sample-to-sample variations. Here we present optical, mechanical and electronic characterization of BN/graphene/BN heterostructures where the angle between layers is changed continuously with a control of 0.2 degrees. In room-temperature experiments, we confirm the layer alignment by measurement of the angle- dependent broadening of the Raman 2D peak, consistent with previous results. As the layers approach alignment, friction between the BN and graphene increases and electronic transport measurements show satellite resistance peaks growing and moving toward the main peaks at charge neutrality. The energy gaps for the main and satellite peaks, as determined from low-temperature measurements, show remarkably different angular dependence. Combining these three measurements in the same device demonstrates the new capability to precisely tune in situ optical, mechanical and electronic properties of a van der Waals heterostructure. Our new experimental technique opens the possibility to study the angle- dependent properties of van der Waals heterostructures and in situ band structure engineering of 2D materials.

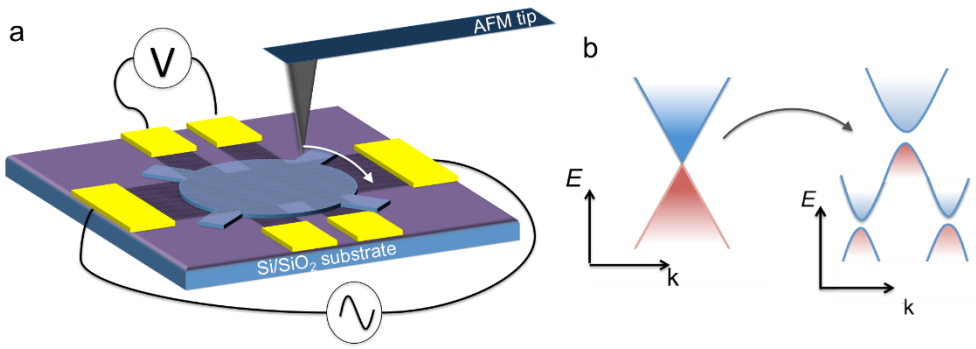

Figure 1 : (a) technique description, an AFM tip is used to rotate the upper most layer of the heterostructure and therefore change the crystallographic orientation between the two layers. (b) Representation of the modification in the electronic band structure of graphene when it is aligned to h-BN.