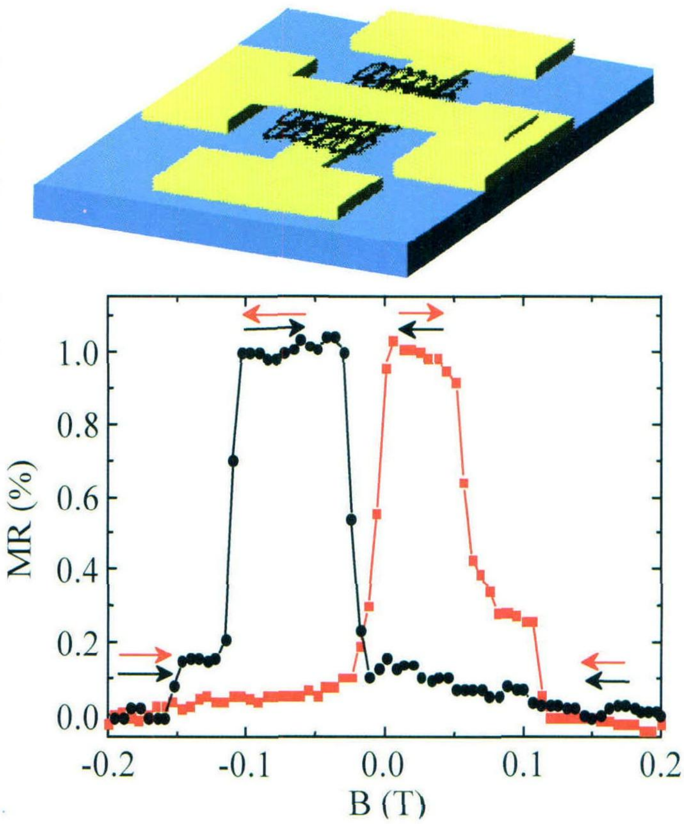
Layer-by-layer assembly of vertically conducting graphene devices



Graphene, comprising a monolayer of carbon atoms packed into a two-dimensional (2D) honeycomb lattice, has received great attention due to its special properties, including massless Dirac fermions, linear dispersion relation near the Dirac cones, high carrier mobility, emerged quantum confinements, and gate-tunable optical transitions. Nevertheless, both the fundamental and application-oriented graphene investigations are commonly concerned with the graphene 2D plane. Vertical graphene devices can extend the investigations and potential applications of graphene to three-dimensionality. The graphene/metal and graphene|graphene interfaces play an important role in such a vertically conducting graphene device. Therefore, it is highly desirable to gain a deep understanding of the graphene interface properties and exploit new functional device effects. Funded by the NSFC, researchers from the Nanolab, Peking University have developed a general method to construct graphene vertical devices with controllable functions via choosing different interfaces between graphene and other materials. This work has recently been published in *Nature Communications* (**2013**, 4: 1921).

To handle such an atomic thick graphene membrane, they developed a graphene/PMMA microstamp method, combined with a micro-manipulator to make site-specific transfer-printing (*Advanced Materials*, **2011**, 23: 3938). By creating an electronic component library, functional devices can be assembled via the bottom-up method. Two types of vertically conducting devices are demonstrated: graphene stacks sandwiched between two Au micro-strips, and between two Co layers. The Au/grapheme/Au junctions exhibit very large magnetoresistance with ratios up to 400% at room temperature, which have potential applications in magnetic field sensors. Moreover, through laying partial graphene sheet on the SiO_2 substrate except the graphene sandwiched between two Au electrodes, the vertical conductance can also be tuned and quantum oscillations can occur under a fixed magnetic field by applying a back gate voltage. Motivated by the novel phenomenon of the vertically conducting Au/Graphene/Au structure and the theoretical prediction of extremely large spin filtering efficiency for the interface between ferromagnetic metal and graphene, Co/Graphene/Co junctions were fabricated. The Co/grapheme/Co junctions display robust spin valve effect at room temperature, suggesting great potential applications in spintronics.

The method of layer-by-layer assembly of graphene developed by the research team provides a route to construct three-dimensionally integrated graphene devices. The graphene microstamps act as building blocks for the bottom-up fabrication of various functional devices. The bottom-up assembly of graphene devices extends the manufacturing strategy from the two-dimensional plane to vertical architecture and provides a new approach for investigating the interactions between assembled graphene layers.