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Gate-tunable stark effect and charge impurities in black phosphorus

Two-dimensional black phosphorus (BP) has sparked enormous research interest due to its high carrier mobility, layer-dependent direct bandgap and outstanding in-plane anisotropic properties. BP is one of the few two-dimensional materials where it is possible to tune the bandgap over a wide energy range from the visible up to the infrared. In this article, we report the observation of a giant Stark effect in electrostatically gated few-layer BP. Using low-temperature scanning tunnelling microscopy (LT-STM), we observed that in few-layer BP, when electrons are injected, a monotonic reduction of the bandgap occurs. The injected electrons compensate the existing defect-induced holes and achieve up to 35.5% bandgap modulation in the light-doping regime. When probed by tunnelling spectroscopy, the local density of states in few-layer BP shows characteristic resonance features arising from layer-dependent sub-band structures due to quantum confinement effects. The demonstration of an electrical gate-controlled giant Stark effect in BP paves the way to designing electro-optic modulators and photodetector devices that can be operated in a wide electromagnetic spectral range. In addition, we also employed LT-STM to manipulate the charge states of intrinsic impurities in black phosphorus together with an aim to understand the spatial structures of bound states near individual acceptors. Our findings open up the new avenue for the investigation into charge transport through single dopants in gated BP nanodevices.

Figures

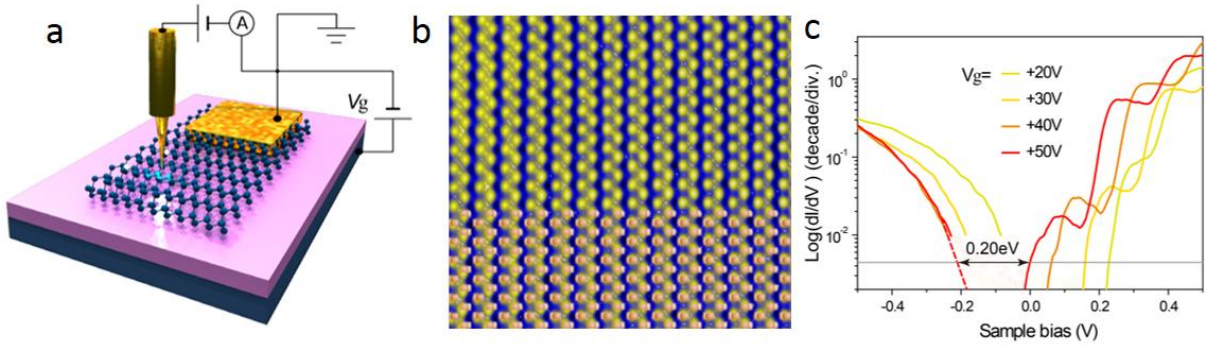

Figure 1: Gate-controlled Stark effect in a few-layer BP flake device (a) Schematic drawing and structural characterisation of a few-layer BP device (b) STM imaging of atomic lattice in BP. (c) Field tunable bandgap measured by local STM spectroscopy.