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Iontronics of 2D materials

2D materials offer a huge number of opportunities in electronic functionalities. One of them is the ease in fabrication of field effect transistor (FET) devices due to their stable and atomically flat surfaces. Actually, FET devices of transition metal chalcogenides and black phosphrous has achieved a high on-off ratios and relatively high mobility and reached observations of quantized Hall effects. Here we review a current status of the electrolyte gating on 2D materials. The conventional FET using a solid dielectrics such as silica, alumina, or h-BN achieves a carrier density in the channel in the order of 10^{12} cm^{-2}. If one replaces the solid gate dielectrics with electrolytes or ionic liquids, the controllable carrier density reaches several times 10^{14} cm^{-2}, which is nearly two orders of magnitude larger than that with solid dielectrics. Thus the electrolyte gating enables us not only to switch the channel current of transistors but also to change the electronic states of the channel materials, such as gate-induced phase transitions and superconductivity. When the device operates in electrostatic modes through the electric double layer formed on the surface of 2D materials, they are called electric double layer transistors (EDLTs). Figure 1 shows a schematic of EDLT devices.

The ability of EDLTs was most clearly demonstrated by the ambipolar transistor operation in MoS_2, which is well known as a n-type semiconductor [1]. Owing to the large carrier tunability, the p-type behavior of MoS_2 was first found with EDLTs. With the ambipolar transistor behavior of WS_2 EDLTs, we also realized a light emitting transistor of circularly polarized light [2]. Furthermore, EDLT has proved its potential by demonstrating an electric field induced superconductivity in MoS_2 using ionic liquid for a gate dielectric [3]. This gate-induced superconductivity was found to be an ideal platform of highly crystalline 2D superconductors [4] by a series of observations of quantum metallic (or vortex glass) states, the enhanced in-plane upper critical field due to spin-orbit interactions, and the nonreciprocal superconducting transport.

The ionic liquid gating was found to induce a structural transition between different charge density wave (CDW) states in 1T-TaS_2. By application of the gate voltage, the commensurate CDW state was completely suppressed, signaling the occurrence of gate-induced phase transitionnbetween the commensurate CDW and nearly commensurate transitions [5].

Another impact of electrolyte gating is the thermoelectric properties of 2D materials with controlled carrier density by EDLT. We demonstrated optimization of thermoelectric power factor in WSe_2[6], also we report the enhanced power factor in FeSe.

References

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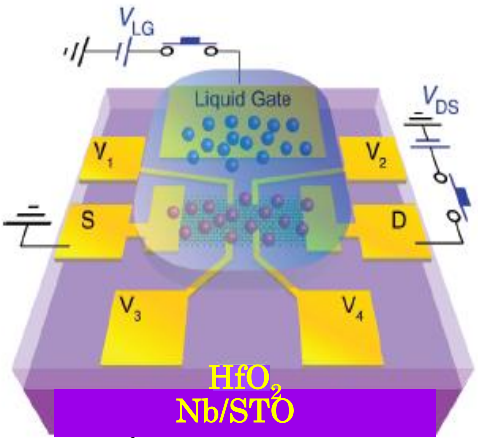

Figure 1: A schematic of EDLT device with 2D materials in a planer gate configuration.