Ion-gating control of optical properties in 2D semiconductors

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Recently, transition metal dichalcogenide (TMDC) monolayers, such as molybdenum disulfide (MoS_2) and tungsten diselenide (WSe_2), have attracted strong attention as novel two-dimensional (2D) semiconducting materials due to their large bandgap (1−2 eV) and excellent transport properties. Moreover, the thickness of monolayer TMDCs is less than 1 nm, which is one of the thinnest materials, and it leads to strong confinement effects, resulting in large binding energy of exciton (> 100 meV) and formation of charged excitons. Particularly, due to their layered structure, there are no dangling-bond states on the surface of TMDC monolayers and it could be an ideal quantum well. Here, we will report the optical functionalities of TMDC monolayers.

In this study, we fabricated ion-gel-gated electric double layer transistors (EDLTs) using large-area TMDC monolayers, MoS_2, WS_2 and WSe_2, grown by chemical vapor deposition [1-8]. The Fermi level of TMDCs can be continuously shifted by applying gate voltage, and we can induce both hole and electron transport in these devices. The hole mobility of WSe_2 can be enhanced up to 90 cm^2/Vs at high carrier density of 10^{14} cm^{-2}, whereas the MoS_2 showed electron mobility of 60 cm^2/Vs. By the combination of MoS_2 and WSe_2, we have demonstrated CMOS inverters [9].

Using EDLT technique, we investigated the optical functionalities of TMDC monolayers. As the first step, the electric field modulation spectroscopy of TMDC monolayers was performed by electric double layer capacitors (EDLCs). Interestingly, The PL spectra of TMDC EDLCs revealed clear peak shifts (~10 meV) and it is the direct signature of quantum confined Stark effect. Based on these successes, we fabricated both electric double layer photodetectors (EDLPD) and light-emitting diodes (EDLED), and the both opto-electric and electro-optic conversion were successfully demonstrated. Finally, we investigated the strength of the Stark effect in WSe_2 EDLED and the giant Stark effect (~40 meV) was realized, suggesting the extremely strong electric field due to electric double layers.

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