Electric-field control of charge carrier density has attracted much attention since it is remarkably simple for modulating physical properties of condensed matters and for exploring new functionalities with a transistor configuration. To realize novel field-effect modulated electronic phenomena in solids, a broad range of attainable carrier density is always required. However, so far, owing to the limitation of dielectric breakdown in most solid dielectrics, the maximum carrier density accumulated in conventional field-effect transistors (FETs) is quite low ($< 10^{13}$ cm$^{-2}$) and thus seriously limits the tunability of electronic states of solids, for example, not sufficient enough to induce insulator-to-superconductor transition. While, recently a new type of transistor, known as electric-double-layer transistor (EDLT), with ionic liquids (ILs) as gate dielectrics have been proved to be able to effectively attain a high carrier density up to levels of around $10^{15}$ cm$^{-2}$ and to realize a large local electric field up to 50mV/cm at liquid/solid interfaces, which are attracting increasing interests because of their potential to greatly tune electronic states and even to create novel states of matter which are impossible or difficult to obtain in conventional methods.

In this presentation, I will discuss the interfacial carrier accumulation within liquid gated EDLTs and their novel tunability of varied electronic phase transitions in oxides, chacogenides and Dirac materials like graphene and topological insulators. I will start with fundamentals of interface electrochemistry and charging mechanism in such fantastic liquid/solid EDL interfaces, for example the competition between electrochemistry charging and electrostatic charging, or the interfacial band alignment and band engineering confirmed with measuring working functions of different ILs by photoemission spectroscopy (PES). Based on these investigations and by further taking great advantages of high carrier density at EDL interfaces ($10^{15}$ cm$^{-2}$), we successfully obtained electric-field-induced insulator-metal transition in ZnO and insulator-superconductor transition in SrTiO$_3$, KTaO$_3$ and ZrNCl. Also we achieved carrier-mediated room temperature ferromagnetism in diluted magnetic semiconductors and giant anomalous Hall effect in magnetically doped topological insulators through modulating the interfacial carrier accumulation. On the other hand, by taking the advantage of large local electric field (50MV/cm), spin-orbit interaction (SOI) and resulting spin splitting of energy band of 2D systems can be regulated with structure inversion asymmetry (SIA) originated from the interfacial band bending and large applied electric fields, and further be used for generating spin-polarized carriers in solids. With magetotransport measurement under liquid gating, I will discuss a field-effect-tuned SOI and a crossover from weak localization (WL) to weak antilocalization (WAL) in 2D systems based on layered chacogenides, WSe$_2$ and SnSe$_2$, and demonstrate the resulting giant Rashba-type and Zeeman-type energy spin splitting with tunable splitting energy in a broad regime of 10-120 meV by simply changing the applied bias, which is supposed to open a new direction of “spin manipulation with liquid” in “interface spintronics”.

Coffee, tea and cookies available in the third floor lounge at 2:45 pm