Electrolyte Gating of Complex Oxides

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Recently, electrolyte gating techniques employing ionic liquids have proven remarkably effective in tuning very large carrier densities at the surfaces of a wide variety of materials. In essence these electrolytes enable electric double layer transistors, the very large specific capacitances (10’s of \( \mu \)F/cm\(^2\)) generating electron/hole densities up to \( 10^{14} - 10^{15} \) cm\(^{-2}\), i.e., doping at significant fractions of an electron/hole per unit cell, sufficient to induce electronic phase transitions. Successes include discovery of superconductivity in KTaO\(_3\), tuning over a dome of superconductivity in MoS\(_2\) and YBa\(_2\)CuO\(_{7-\delta}\), and electrical control of the insulator-metal transition in VO\(_2\), although many questions remain. Uncertainties include the true doping mechanism (i.e., purely electrostatic vs. electrochemical (e.g., redox) based), the relation between 2D surface and bulk chemical doping, the role of electrostatic disorder, and the universality of the approach. In this seminar I will review the application of electrolyte gating using ionic gels (or ion gels), which enable simple processing of all-solid-state devices [e.g., 1-3]. I will mostly discuss application to the model perovskite oxide ferromagnet La\(_{1-x}\)Sr\(_x\)CoO\(_3\). In this system our findings greatly clarify the issue of electrostatic vs. electrochemical response, resulting in a picture where electrostatic gating vs. oxygen vacancy formation can be understood and predicted based on initial doping, bias polarity, and redox stability [4,5]. By understanding electrostatics vs. electrochemistry [4,5], as well as the theory of electrostatically-induced percolation [6], we have optimized electrostatic gating to the point where we achieve reversible electrical control over resistivity, magnetoresistance, magnetization, and Curie temperature over a wide range. We achieve Curie temperature modulation over a 150 K range, for example, a record for electrostatic control of complex oxides by any means, and for electrostatic electrolyte gating of any magnetic material [7]. These results highlight the extraordinary utility of electrolytes for control of materials functionality, particularly voltage-control of magnetism.

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