Large modulation of electronic states in InAs quantum dots by electric-double-layer gating

K. Shibata [1], H.T. Yuan [2], Y. Iwasa [2,3] and K. Hirakawa [1,4]

[1]*INQIE and IIS, University of Tokyo, 4-6-1 Komaba, Meguro-ku, Tokyo 153-8505, Japan*
[2]*QPEC and Department of Applied Physics, University of Tokyo, Tokyo, 113-8656, Japan*
[3]*Correlated Electron Research Group, RIKEN, Wako 351-0198, Japan*
[4]*CREST-JST, 4-1-8 Honcho, Kawaguchi, Saitama 332-0012, Japan*

Electrical manipulation and read-out of quantum mechanical states in zero-dimensional (0D) nanostructures by nanogap metal electrodes is expected to bring about great innovation in information-communication technology and have been intensively studied [1]. However, in these 0D nanostructures, the electrical tunability of the quantum states is rather limited due to the screening of the gate electric field by the nanogap metal electrodes. Electric-double-layer (EDL) gating with ionic liquids as gate dielectrics is powerful in tuning the Fermi energy in solids [2]. The EDL formed at liquid/solid interfaces (Fig. 1), which functions as a huge capacitance, can accumulate or deplete charge carriers over a large range. However, EDL gating has not been applied to 0D nanostructures yet.

In this work, we demonstrate a new way of electric field gating which realizes wide-range electrical tunability of 0D quantum states by adopting liquid-gated EDL transistor structures on single self-assembled InAs quantum dots (QDs) coupled to nanogap metal electrodes (Fig. 1). The transport characteristics are dramatically modulated by a small EDL-gate voltage, V_{EDL}, applied between the EDL-gate electrode and the QD (Fig. 2(a)-2(c)). The energy level spacing between *s*- and *p*-orbitals, $\Delta E_{s\text{-}p}$, was modulated from $\Delta E_{s\text{-}p}$ ~22 meV (V_{EDL} = -0.5 V) to ~10 meV (V_{EDL} = 0.1 V). The charging energy and the electron g-factor were also modulated in a wide range. The efficiency of gating is 10-100 times higher in EDL gating than that in the conventional solid-gating techniques (Fig. 2(d)). The EDL gating on QDs provides not only high tunability of electronic states but also good compatibility with optical manipulation of single electron charge/spin states [3], which is essential for their application to quantum information processing.

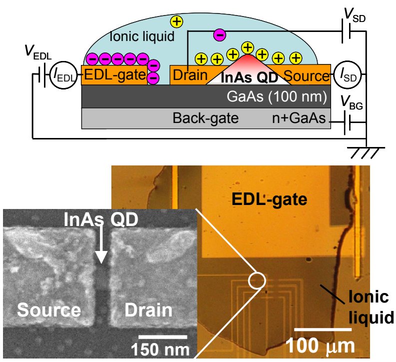

Fig. 1: Schematic illustration (upper) and the microscope images (lower) of QD-EDL transistors.

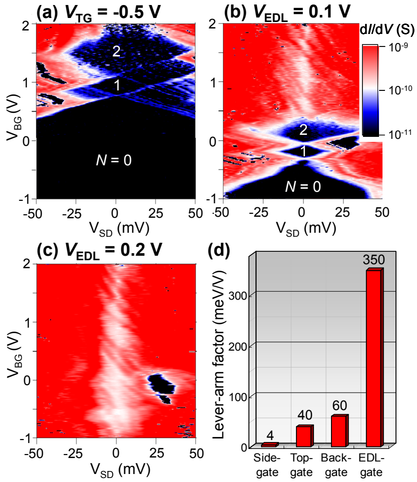

Fig. 2(a)-(c) Coulomb stability diagrams for different EDL-gate voltages. (d) Comparison of the gating efficiency with various methods.

[1] D. L. Klein et al., Nature **389**, 699 (1997).
[2] K. Ueno et al., Nature Mater. **7**, 855 (2008).
[3] K. Shibata et al., Phys. Rev. Lett. **109**, 077401 (2012).