Strain-tunable superconducting field-effect transistor with an organic strongly-correlated electron system

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In the past half century, field-induced superconductivity in condensed matter has been one of the main subjects in the field of materials science. Recent advances in the electrostatic carrier-doping concepts such as electric-double-layer transistor configuration realized an accumulation of extremely high carrier density and field-induced superconductivity in inorganic materials.

Recently, we have demonstrated the first field-induced superconductivity in the organic-based field-effect transistor (FET) [1,2]. We used a thin single crystal of κ-(BEDT-TTF)2Cu[N(CN)2]Br (κ-Br) laminated on Nb-doped SrTiO3 substrates. Novel concept of this device was to take advantage of the soft lattice of organics to tune the inter-molecular interaction by strain effects from the substrates. Bulk κ-Br is a strongly-correlated molecular superconductor (TC = 11.6 K) that neighbors Mott-insulating phase. The ground state of κ-Br on this device was tuned in the vicinity of a band-width-controlled Mott transition by tensile strain from the relatively harder substrate. As a result, field-induced superconductivity was realized by electrostatic carrier doping into κ-Br near the bandwidth-controlled Mott transition. However, substrate-exchange is needed to control the strain effects, that is, the strain effects in this device is not able to be controlled continuously.

In this study, we fabricated a novel type of organic FET, in which strain effects can be finely tuned continuously (Fig. 1). The device has a bottom-gate FET configuration where a thin single crystal of κ-(BEDT-TTF)2Cu[N(CN)2]Cl (κ-Cl) is laminated on a plastic-based flexible substrate. In this device, desired strain effects can be induced by bending the substrate from the back side of the substrate. Hence, this device enabled co-regulation of "bandwidth" and "band-filling" in κ-Cl by combination of the field-effects and the strain-effects. Finally, field-induced emergence of superconducting fractions at low temperature was realized by electrostatic carrier doping into κ-Cl near the bandwidth-controlled Mott transition [3]. Furthermore, this novel strategy will be useful for not only current material but also any other organic/inorganic materials to explore undiscovered electronic phases.

Fig. 1 Schematic illustration for the strain-tunable superconducting field-effect transistor.