Field effect on molcular conductors

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Field effect transistor is not only an electronic device for application use but also a powerful tool for solid state physics. For example, gate-modulated behavior of zero-gap conductors such as graphene is one of the most interesting subjects in recent material research. Another example is the gate-induced enhancement of Tc of superconductivity of highly correlated electron systems such as Nb-doped $SrTiO_3$, which gives rise to significant insight about the origin of high-Tc superconductivity. Molecular conductor shares many low-dimensional electronic properties such as zero-gap state, charge ordering, Pierls instability, and non-BCS superconductivity with inorganic correlated systems, but precise control of the physical properties of molecular conductors has been long relying on physical and/or chemical pressure that tunes transfer integrals between molecules. For example, enhancement of the transfer integral effectively reduces the electron-electron correlation (U/W) in kappa-(BEDT-TTF)$_2$Cu[N(CN)$_2$]Cl and in the vicinity of antiferromagnetic insulator to metal transition unconventional superconductivity appears. The band filling control by the field effect is believed to possess similar correlation-reducing effect, but lack of appropriate procedure to fabricate device configuration with molecular conductors has kept researchers away from considering such experiments. Several groups have reported field effect on molecular conductors recently, but the ranges of material and temperature in their measurements are quite limited. In this presentation, we report versatile method for the fabrication of field effect device of molecular conductor and the results of the measurement. (BEDT-TTF = bis(ethylenedithio)tetrathiafulvalene)

Our method employs electrochemical growth of thin crystals and transfer of them onto a substrate with source, drain, and gate electrodes. Before examining the field effect, it is necessary to survey the thermal influence of the substrate on the single crystal of molecular conductors. When the substrate is made of SiO_2/Si, the thermal expansion coefficient of the substrate is far smaller than those of the organic samples. Therefore, the sample is expanded in directions parallel to the substrate surface at low temperature. For example, kappa-(BEDT-TTF)$_2$Cu[N(CN)$_2$]Br is normally a superconductor in its ground state, but when it is fixed on a hard silicon substrate it falls into the insulating ground state due to the pseudo negative pressure from the substrate. We have applied gate voltage to this insulating sample on SiO_2/Si substrate and observed its transistor behavior. The ON/OFF ratio reaches more than 1000 and the activation energy has been considerably reduced by applying positive gate voltage (Fig. 1, Fig. 2). It is interesting that there is no apparent threshold behavior for this device, which seems to be a unique character of Mott-insulator based transistor. alpha-(BEDT-TTF)$_2$I$_3$ is in a zero-gap state under hydrostatic pressure, and at ambient pressure it exhibit metal-insulator transition at 135 K. The insulating phase is a charge ordering state. Before we apply gate voltage and pressure simultaneously, we have measured transistor behavior of the charge ordered insulating phase at ambient pressure to check the device quality. With this insulating sample again, we have observed n-type transistor behavior with moderate ON/OFF ratio. Results using plastic substrates will also be presented.

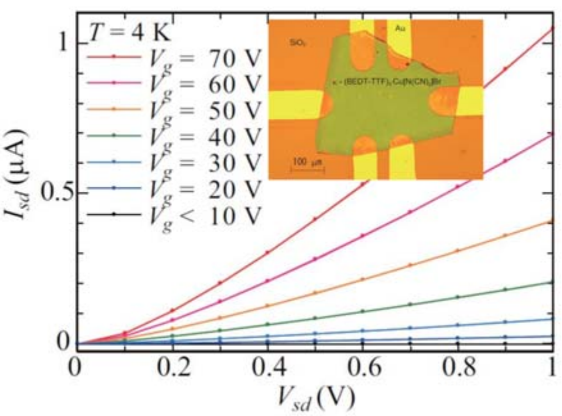

Fig.1 I-V characteristics and microscope image of the device

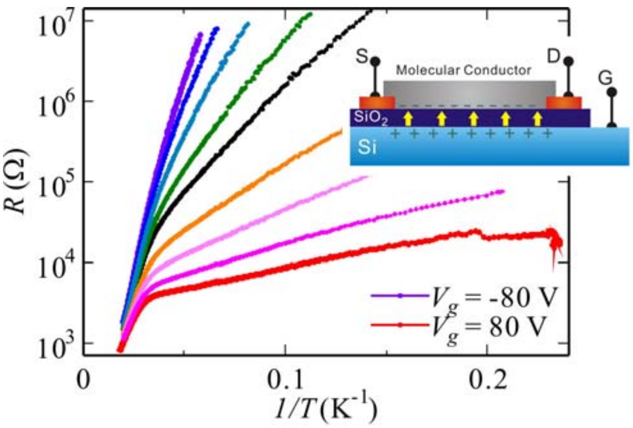

Fig.2 Arrhenius plot of the resistivity and the device configuration