

Complementary single molecule transistors

Takhee Lee^{1*}, Hyunwook Song¹, Youngsang Kim², Yun Hee Jang¹, Heejun Jeong², and Mark A. Reed³

¹Department of Nanobio Materials and Electronics, Department of Materials Science and Engineering, Gwangju Institute of Science and Technology, Gwangju 500-712, Korea

²Department of Applied Physics, Hanyang University, Ansan 426-791, Korea

³Departments of Electrical Engineering and Applied Physics, Yale University, New Haven, CT 06520, USA

Field-effect transistors rely on the gated electrostatic modulation of the channel charge by changing the relative position of the conduction and valance bands with respect to the electrodes. In molecular-scale devices, a longstanding challenge has been the ability to create a true three-terminal device that operates in this manner. In this presentation, we report the first observation of a single molecule transistor where transport current is directly controlled by molecular orbital modulation.

As illustrated in the inset of Fig. 1, individual molecules are connected to source and drain electrodes with a bottom-gate control electrode in a FET configuration. We have examined two prototype molecules: (a) the control, octanedithiol (ODT) with an alkyl s-backbone as a saturated aliphatic molecule, and (b) the active device, benzenedithiol (BDT) with a delocalized p-electron aromatic ring as a conjugated molecule. Figure 1 shows representative characteristics of a Au-BDT-Au junction. The measurement of a transition voltage (V_{trans}) from direct tunneling regime to Fowler-Nordheim tunneling regime enables a calibration of the energy barrier height in molecular junctions that is given by the energy difference between the electrode Fermi energy (E_F) and the nearest molecular orbital (highest occupied molecular orbital, HOMO, or lowest unoccupied molecular orbital, LUMO). We observed the V_{trans} for Au-BDT-Au junctions shifted to a lower bias as a more negative V_G is applied. These results indicate that the BDT molecular transistor behaves as a “p-type” HOMO-mediated tunneling devices. Inelastic electron tunneling spectroscopy (IETS) was also performed, to verify the identity of the molecule in the junction, and to determine the amount of orbital coupling [1].

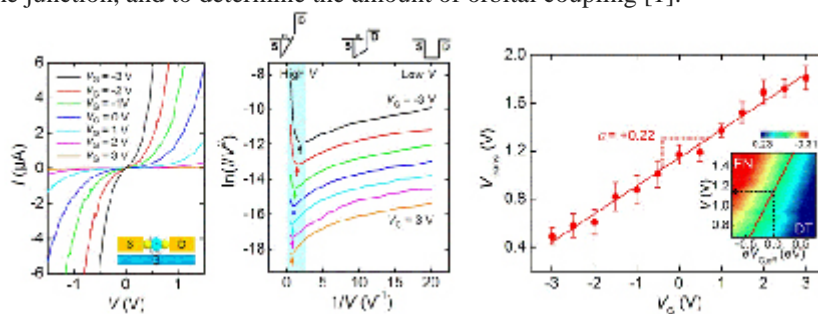
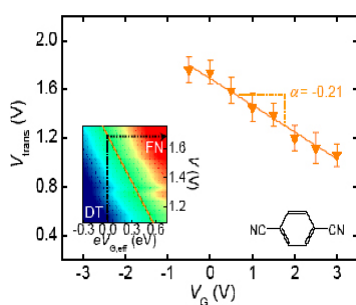


Fig. 1. $I(V)$, Fowler-Nordheim, and HOMO level shift characteristics of a BDT molecular transistor.



We demonstrate that a change of the molecule attachment endgroups (specifically, from thiol, -SH to cyanide, -CN) can change the orbital alignment with respect to the contact Fermi level, transforming the behavior from HOMO-dominated (i.e., “p-type”) to LUMO-dominated transport (i.e., “n-type”). These results show that a complementary set of true molecular transistors can be created with appropriate molecular and endgroup design.

Fig. 2. LUMO level shift characteristics of a “n-type” benzenedicyanide (BDCN) transistor.

[1] H. Song, Y. Kim, Y. H. Jang, H. Jeong, M. A. Reed, and T. Lee, *Nature* 462, 1039 (2009).

†Present address: Department of Physics, University of Konstanz, D-78457 Konstanz, Germany.