Supporting Information

3D Hollow Framework Silver Nanowire Electrodes for High-Performance Bottom-Contact Organic Transistors

Jiye Kim[†], So Hee Lee[§], Haekyoung Kim[§], Se Hyun Kim[‡]*, and Chan Eon Park[†]**

[†] POSTECH Organic Electronics Laboratory, Department of Chemical Engineering, Pohang University of Science and Technology, 77 Cheongam-Ro, Nam-Gu, Pohang, Gyungbuk, 790-784, Korea. E-mail: cep@postech.ac.kr

[‡]Department of Nano, Medical and Polymer Materials, Yeungnam University, 280 Daehak-Ro, Gyungsan, Gyeongbuk, 712-749, Korea. E-mail: shkim97@yu.ac.kr

[§]School of Materials Science and Engineering, Yeungnam University, 280 Daehak-Ro, Gyungsan, Gyeongbuk, 712-749, Korea. E-mail: hkkim@ynu.ac.kr

The contact resistance can be determined with the transmission line method (TLM).[1,2] Figure S1 shows channel width-normalized total resistance ($R_{\text{total}}W$) as a function of channel length using bottom- and top-contact AgNWs, Ag, and Au electrodes. $R_{\text{total}}W$ is the sum of the channel resistance (R_{C}) and the contact resistance in linear regime.

$$R_{\text{total}}W = R_{\text{C}}W + \frac{L}{\mu C_{\text{p}}(V_{\text{G}} - V_{\text{th}})}$$

where $R_{\text{total}}W$ is the total resistance normalized to the channel width, $R_{\text{C}}W$ is the width-normalized contact resistance, L is the channel length, μ is the intrinsic channel mobility, C_{P} is the dielectric capacitance per unit area, V_{G} is the gate voltage, and V_{th} is the threshold voltage. In the TLM analysis, $R_{\text{total}}W$ is plotted as a function of channel length, so that the linear fit yields $R_{\text{C}}W$ (by extrapolating to L = 0).

In Figure S1, the width-normalized total resistances of OFETs based on all electrodes at a gate voltage of −40 V are plotted as a function of channel length. The linear fits yield width-normalized contact resistances of 1.5×10^{5} Ω cm for AgNWs (bottom-contact), 3.6×10^{6} Ω cm for Ag (bottom-contact), and 1.3×10^{4} Ω cm for Au (top-contact), respectively.

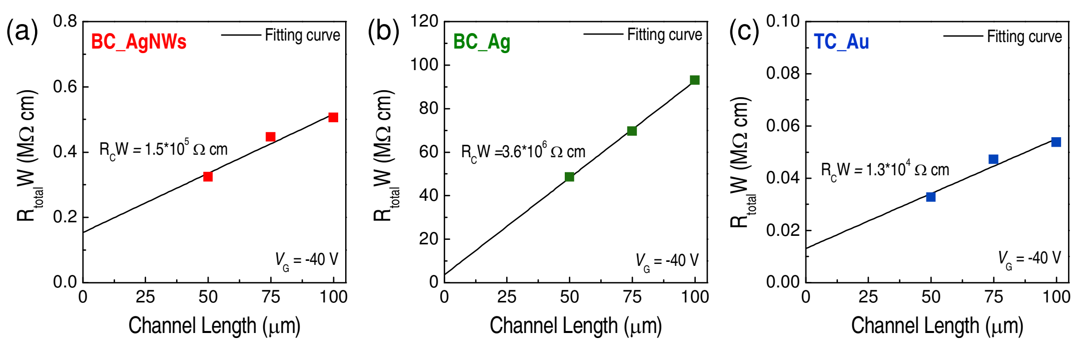

Figure S1 Channel width-normal total resistance as a function of channel length for pentacene OFETs with (a) bottom contact AgNWs, (b) bottom contact Ag, and (c) top-contact Au as source/drain electrodes at V_{G} = -40 V.

The injection barrier of can be speculated from the work function of metal, which was measured by UPS experiment, and HOMO level of organic materials. Figure S2 presents a summary of the results for the interfaces between electrode and pentacene. The hole injection barriers ($\Phi_{barrier}$) between electrode and pentacene were calculated using the equation,[3]

$$\Phi_{barrier} = E_{HOMO\ (organic)} - \Phi_{metal}$$

Here, $E_{HOMO\ (organic)}$ and $E_{HOMO\ (organic)}$ are HOMO level of pentacene (or PVP) and the work function of the metal, respectively. HOMO level of pentacene is estimated from literature survey. The hole injection barrier is 0.62 eV for pentacene/Ag. In case of AgNW electrode, the hole injection barrier is induced by adsorbed PVP on the AgNWs. As shown in Figure S2(b), PVP/AgNW shows high hole injection barrier of 2.36 eV.

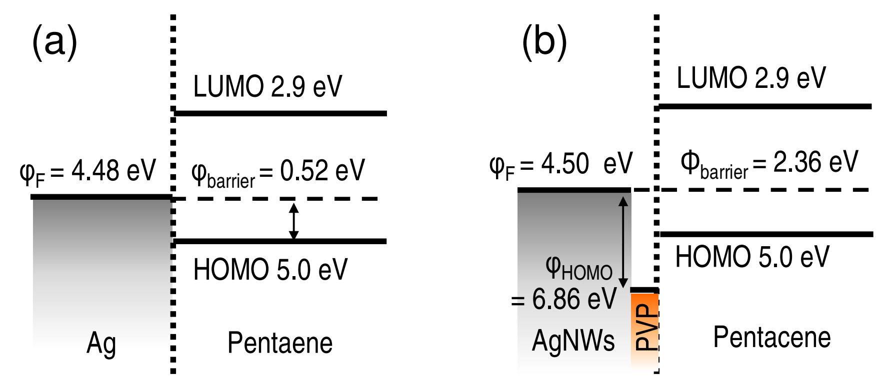

Figure S2 The band diagram of the interface between metals and pentacene: (a) pentacene/Ag and (b) pentacene/PVP/AgNWs

REFERENCE

(1) Kraft, U.; Anthony, J. E.; Ripaud, E.; Loth, M. a.; Weber, E.; Klauk, H. Low-Voltage Organic Transistors Based on Tetraceno[2,3-b]thiophene: Contact Resistance and Air Stability, *Chem. Mater.* **2015**, *27*, 998–1004.

(2) Berger, H. H. Contact Resistance and Contact Resistivity, *J. Electrochem. Soc.* **1972**, *119* , 507.

(3) Ishii, H.; Sugiyama, K.; Ito, E.; Seki, K. Energy Level Alignment and Interfacial Electronic Structures at Organic/Metal and Organic/Organic Interfaces, *Adv. Mater.* **1999**, *11* , 605–625.