Inkjet Printing of Organic Metal Electrodes for Contact Engineering of Organic Field Effect Transistors

T. Hasegawa, M. Hiraoka, Y. Takahashi, T. Yamada, and Y. Tokura

Correlated Electron Research Center (CERC), National Institute of Advanced Industrial Science and Technology (AIST), 1-1-1 Higashi, Tsukuba 305-8562, Japan

Abstract

Here we present and discuss useful nature of highly conductive organic donor-acceptor charge-transfer (CT) compounds which are found to provide engineered electrical contacts with organic molecular semiconductors. It is firstly shown that the carrier injections in organic field-effect transistors (OFETs) can be tuned and optimized by the use of vacuum-sublimated conductive CT compound films as the source/drain electrodes. Then it is presented that the solution processible inkjet printing (IJP) is applicable to the fabrication of patterned thin films using conductive CT compounds. Based on the field-effect characteristics of the OFETs employing the inkjet-printed organic electrodes, we discuss the potential of organic/organic heterointerfaces.

1. Introduction

Organic field effect transistors (OFETs) are now envisioned as key components in future organic electronics for their potential applications to electronic circuitry as well as active matrix elements in a variety of large, flexible, and low-cost electronics devices [1]. The OFETs conventionally employ the single molecular and nominally intrinsic semiconducting π-electron materials as the channels, whose electrical contacts are formed directly with inorganic metals. This simple feature, closely associated with the difficulty in controlled chemical doping of molecular solids, might be possible in molecular materials in which the deep interface states are seldom formed within the bandgap due to the weak van der Waals intermolecular interactions. Meanwhile, the use of direct metal/intrinsic-semiconductor contacts implies that the OFETs still stand at the premature stage of the developments in terms of the process technology as compared to inorganic semiconductor devices. Particularly, carrier injections from source/drain electrodes to channels often become critically important for the performance of OFETs in which the electric fields for the current conduction are much smaller than those in organic light emitting diodes (OLEDs). Nevertheless, no reliable and generalized method has yet been established to improve the carrier injection efficiency at the channel/electrode interfaces in the OFETs.

Recently we successfully demonstrated that highly conductive donor-acceptor charge-transfer (CT) compounds, the well-known two-component π-electron materials composed of electron donor and electron acceptor molecules [2], are useful to provide engineered electrical contacts with the channels in OFETs. Here we demonstrate that the use of CT compounds enables us to control the p- and n-type operations as well as to optimize the efficiencies in carrier injections [3-4]. We present the results on single crystal devices employing vaccum-sublimated metallic thin films of TTF-TCNQ [TTF = tetrathiafulvalene and TCNQ = tetracyanoquinodimethane] analogues as the electrodes. We then present that it is also possible to fabricate patterned thin films of the conductive CT compounds by solution processible inkjet printing (IJP) technique [5]. We discuss the performance of pentacene thin film OFETs, where the top-contact and bottom-contact are inkjet-printed organic electrodes using highly conductive CT compounds.

2. Potential of Organic Electrodes

2.1. Optimized Injections

In organic molecular semiconductors, the Mott-Schottky vacuum level alignment rule is basically expected to hold at the metal/semiconductor interfaces, unless the molecules suffer appreciable chemical or structural change at around the interfaces under the inorganic metal depositions. In such cases, carrier injections into molecular semiconductors might be optimized by choosing electrode materials with appropriate work functions, which is close to the highest occupied molecular orbital (HOMO) or lowest unoccupied molecular orbital (LUMO) of the channels, for hole or electron injections, respectively. We suggest that highly conductive CT compounds are most promising as the components of electrodes, since identical molecular levels are available, when we adopt CT compounds composed of the same molecules as the channels. In Figure 1, we show the schematic band diagrams for the metal/semiconductor contacts that afford optimized hole and electron injections, respectively. By using the conductive CT compounds, the Fermi energy could be set at the midst of the valence bands (HOMO levels) or conduction bands (LUMO levels) of the channels. Thus it is expected that the formation of this type of all-organic metal/semiconductor contacts should automatically provide minimal contact potential at the metal/semiconductor interfaces.

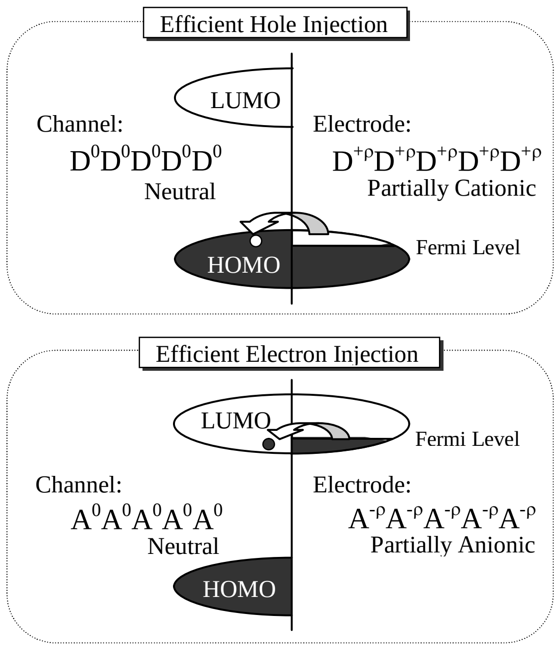

Figure 1 Band diagrams for metal/semiconductor contacts. Use of the CT metals composed of molecules, identical with the channels but partially cationic or anionic, as the source/drain electrodes provides efficient hole or electron injections at the metal/semiconductor contacts, respectively.