

# Parasitic resistance in bottom-contact pentacene thin-film transistors that use water-dispersible polyaniline electrodes

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## Introduction

Organic thin-film transistors (TFT) have received considerable attention due to promises of low manufacturing costs, ease of processibility, and extendibility to flexible circuits. The feasibility of organic TFTs has largely been demonstrated with devices that use metal source and drain electrodes, such as gold and palladium. Such devices, when fabricated in the bottom-contact (BC) configuration, exhibit pronounced non-linear current-voltage (I-V) characteristics in the low source-drain voltage regime [1]. This phenomenon has been attributed to the presence of a large dipole barrier at the organic semiconductor/metal interface [2]. It has also been hypothesized that this dipole barrier can be decreased through the incorporation of organic, rather than metallic, conductors as electrodes. For example, Koch et al. found that organic semiconductor/conducting polymer interfaces, e.g. pentacene/poly(3,4-ethylenedioxythiophene)-poly(styrenesulfonate), significantly reduce the hole injection barrier and the interfacial dipole barrier [3]. Lefenfeld et al. also showed that BC pentacene TFTs that use polyaniline (PANI)/single-wall carbon nanotube electrodes exhibit decreased contact resistance at the interface [4]. This paper presents an experimental study of parasitic resistance in BC pentacene TFTs that use water-dispersible PANI electrodes. PANI electrodes were fabricated using our recent stamp-and-spin-cast technique [5]. Thermal evaporation of pentacene directly onto the channel region completes the circuit. We extracted the parasitic resistance using the TFTs with different channel lengths. Quantitative comparison between the contribution of the PANI electrode bulk resistance and the contact resistance at the pentacene/PANI electrode interface to the parasitic resistance indicates negligible contact resistance at the pentacene/PANI interface.

## Experimental

Water-dispersible PANI is prepared by oxidative polymerization of aniline monomer in the presence of a polymeric acid, i.e. poly(2-acrylamido-2-methyl-1-propane-sulfonic acid), PAAMPSA. The synthesis details have been described in Refs. [6,7]. Patterning water-dispersible PANI-PAAMPSA exploits its hydrophilic nature. To pattern PANI-PAAMPSA electrodes, we etch a highly n-doped Si (0.004 ohms-cm) substrate with 3000 angstroms of thermally-grown SiO<sub>2</sub> in a solution of H<sub>2</sub>O<sub>2</sub>/HCl for 10 min and subsequently rinse the substrate thoroughly with DI water, acetone, and isopropyl alcohol. A 20 min UV/ozone treatment further removes residual hydrocarbons from the surface, thereby rendering it hydrophilic. Elastomeric stamps with inverse relief features compared to the final electrode patterns are fabricated using Sylgard184 polydimethylsiloxane (PDMS) prepolymer from Dow Corning according to established procedures [8,9]. The stamp is inked with a 5mM OTS (n-octadecyltrichlorosilane) in hexanes solution before it is brought into contact with the treated substrate. In the regions of stamp/substrate contact, condensation reaction occurs between

OTS and the hydroxyl groups on surface. This reaction results in the formation of a hydrophobic molecular layer while the non-contacted regions on the substrate remain hydrophilic.

A 10%wt PANI-PAAMPSA aqueous solution is then spun-cast on the OTS-patterned substrate. Due to strong interactions between PANI-PAAMPSA and the remaining surface hydroxyl groups, PANI-PAAMPSA selectively adsorbs on the hydrophilic regions thereby resulting in a conductive pattern after spinning. The thicknesses of the PANI-PAAMPSA patterns range between 1 and 2 microns. To extract the contact resistance between pentacene and PANI-PAAMPSA electrodes, a series of source and drain electrodes with varying channel lengths (30, 40, 50, 60 and 80 microns), but the same channel width (800 microns) have been patterned [10].

We then thermally evaporate 150 angstroms of pentacene (p-type organic semiconductor) through a shadow mask (at 0.5-0.7 angstrom/s) directly onto the channel regions to create BC TFTs. Current-voltage (I-V) characteristics of these devices were acquired in the dark on a probe station equipped with an Agilent parameter analyzer to minimize pentacene photodoping.

## Results and Discussion

The field-effect characteristics of TFTs that incorporate PANI-PAAMPSA source and drain electrodes appear near-ideal, with distinct linear and saturation regimes. More interestingly, the I-V characteristics in the linear regime exhibit ideal ohmic behavior, contrary to those of pentacene TFTs with Au electrodes fabricated at the same time. That linear I-V characteristics are observed in the low source-drain voltage regime is a strong indication of negligible contact resistance at the semiconductor/electrode interface. To verify this, we analyzed our parasitic resistance data, collected as a function of channel length, using a simple resistors-in-series model. Because PANI-PAAMPSA exhibits a low conductivity (0.05 S/cm from four-probe measurements), the parasitic resistance in our model consists of the PANI-PAAMPSA electrode bulk resistance, in addition to the contact resistance at the semiconductor/electrode interface. Specifically, we found that the parasitic resistance at a gate voltage of -40V is 530 kilo-ohms, which is comparable to the bulk resistance of PANI-PAAMPSA electrodes of 500 kilo-ohms. The parasitic resistance is therefore largely dominated by the bulk resistance of PANI-PAAMPSA electrodes, and not by the contact resistance at the pentacene/PANI-PAAMPSA interface.

The majority of the TFTs with PANI-PAAMPSA electrodes exhibit similar characteristics with mobilities in both linear regime and the saturation regime ranging from 0.01-0.03 cm<sup>2</sup>/V-sec, on/off current ratios of 10<sup>3</sup>, and subthreshold slopes as low as 5V/decade. Similar BC TFTs with Au source and drain electrodes exhibit saturation mobilities that are an order of magnitude higher. We speculate that the reduction in mobility in the pentacene/PANI-PAAMPSA TFTs arises from poor charge transport due to the low conductivity of PANI-PAAMPSA. It is, therefore, expected that an increase in PANI-PAAMPSA conductivity will improve the overall device performance. Experiments to enhance the bulk conductivity of PANI-PAAMPSA are currently underway.

## References

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