Organic complementary-like inverters employing methanofullerene-based ambipolar field-effect transistors

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We demonstrate a complementary-like inverter comprised of two identical ambipolar field-effect transistors based on the solution processable methanofullerene [6,6]-phenyl-C61-butyric acid methyl ester (PCBM). The transistors are capable of operating in both the p- and n-channel regimes depending upon the bias conditions. However, in the p-channel regime transistor operation is severely contact limited. We attribute this to the presence of a large injection barrier for holes at the Au/PCBM interface. Despite this barrier the inverter operates in both the first and third quadrant of the voltage output versus voltage input plot exhibiting a maximum gain in the order of 20. Since the inverter represents the basic building block of most logic circuits we anticipate that other complementary-like circuits can be realized by this approach. © 2004 American Institute of Physics. [DOI: 10.1063/1.1812577]

Organic field-effect transistors (OFETs) are currently the focus of intense research efforts in numerous academic and industrial research laboratories around the world. Over the past decade OFETs have emerged as promising candidates for electronic device applications requiring low cost and large area coverage, mechanical flexibility, and low temperature processing. 1 Several groups have demonstrated OFET-based circuits with performances sufficient for practical applications. Few examples of such applications include switching devices for flat panel displays 2–4 and integrated circuits. 4–6 To date the largest organics-based electronic circuit reported is the standard logic based 32-stage shift register of C60 /α-6T which consists of 1888 transistors capable of operating at a frequency of 5 kHz. 4 As the number of transistors per circuit increases there is an increasing need for circuits characterized by low power dissipation, high noise margin, and greater operation stability. In silicon-based microelectronics such requirements are met through the use of complementary metal–oxide–semiconductor (CMOS) logic where an n- and a p-type transistor are combined to built logic circuits. Indeed, examples of organic CMOS logic have show that it is possible to make large-scale integrated circuits (up to 864 transistors per circuit) with much lower power dissipation. 6 In the work by Crone et al., however, the transistor channels had to be spatially separated in order to facilitate the separate vacuum deposition of the two semiconductors (an n- and a p-type), thus making circuit fabrication difficult and potentially expensive.

Recently an alternative approach towards organic CMOS circuits has been proposed. 7 In their work Meijer et al. have demonstrated that by employing identical ambipolar OFETs based on polymer-small molecule interpenetrating networks as well as narrow band gap polymers, CMOS-like voltage inverters can be fabricated. This approach makes full use of

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0.75–40 µm. A 10 nm layer of titanium was used acting as an adhesion layer for the gold on SiO₂. The SiO₂ layer was treated with the primer hexamethyldisilazane prior to semi-conductor deposition in order to passivate its surface. The drain electrode was contained within a circular source electrode [inset Fig. 1(a)] in order to minimize parasitic leakage currents. Films were spun from a 10 mg/ml solution of PCBM in chlorobenzene at 500 rpm for 1 min. The molecular structure of PCBM is shown in inset of Figs. 1(a) and 1(b). All freshly prepared devices were annealed in vacuum of 10⁻⁷ mbar at 120 °C for several hours. All electrical measurements were performed in high vacuum of 10⁻⁷ mbar at room temperature (24 °C) using an HP 4156B semiconductor parameter analyzer.

Figure 1 shows the transfer characteristics of an ambipolar PCBM based OFET (L=20 µm, W=1000 µm) in electron enhancement [Fig. 1(a)] and hole enhancement [Fig. 1(b)] operating mode. Maximum electron and hole mobilities measured are 1×10⁻² cm²/V s (at V_G=20 V, V_D=20 V), and 8×10⁻³ cm²/V s (at V_G=−75 V, V_D=−20 V), respectively. From Fig. 1(b) it is evident that for p-channel operation the transistor exhibit a high switch-on voltage of approximately −40 V. This observation suggests either the presence of a significant density of hole traps at the SiO₂/PCBM interface and/or the existence of a large contact barrier for hole injection from Au into the higher occupied molecular orbital of PCBM. The barrier to electron injection from Au into the lower unoccupied molecular orbital (LUMO) of PCBM, on the other hand, appears to be relatively small exhibiting a switch-on voltage of only +3 V [see Fig. 1(a)].
In summary, we have demonstrated a complementary-like voltage inverter comprised of two identical ambipolar OFETs based on the solution processable methanofullerene PCBM. The inverter can function at room temperature exhibiting a maximum voltage gain of 18. This is one of the highest gains reported to date for OFET based inverters. Furthermore, the use of high mobility ambipolar organic semiconductors such as PCBM can be viewed as a significant step towards organic-based CMOS-like technology.

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