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Physical force-sensitive touch responses in liquid crystal-gated-organic field-effect transistors with polymer dipole control layers

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A B S T R A C T

We report the sensing performances of liquid crystal-gated-organic field-effect transistors with a polymer dipole layer (DCL-LC-g-OFETs) upon physical touches. The DCL-LC-g-OFET devices, which were fabricated by employing 4-cyano-4'-pentylbiphenyl (5CB) as a sensing gate insulating layer, poly(methyl methacrylate) (PMMA) DCL, and 50 nm-thick poly(3-hexylthiophene) (P3HT) channel layer, which were optically semi-transparent and exhibited p-type transistor behavior. A pencil-like load (0.6 g–4.8 g) was introduced as a means for physical touch, while a human finger was used to examine the practical sensing capability of devices. Results showed that the drain current responded quickly upon physical touch and increased linearly with the strength of physical touch. The response time upon physical touch was slightly affected by the touch strength but was as fast as less than 1 s, while the drain current signals were quite reproducible and stable even after repeated physical touches. The present DCL-LC-g-OFET devices exhibited excellent sensing performances and reproducibility upon the human finger touch.

1. Introduction

Organic electronic devices have been extensively studied due to their advantages over inorganic electronic devices because their performances can be tuned with a variety of organic semiconducting materials that can deliver unique electronic properties through the sophisticated design of chemical structures [1–5]. In particular, recent device approaches have mostly employed plastic film substrates leading to flexible electronic devices in order to maximize the advantages of organic electronic devices compared to conventional inorganic devices [6–10]. Since the successful launching of organic light-emitting devices (OLEDs) in market, further efforts toward commercialization have been attempted for various organic electronic devices including organic solar cells (OSCs), organic field-effect transistors (OFETs), organic memory devices (OMDs), etc. [10–19].

Of such various organic electronic devices, OFETs have been still spotlighted because of their potentials for replacing conventional inorganic transistors that are currently applied for memory devices, central processing units in computers, and driving backplanes for active matrix displays [20–25]. However, the charge carrier mobility of OFETs is yet far behind that of inorganic transistors, even though gradual advances have been made on a laboratory scale [26–30]. On this account, applications of OFETs have been diversified into biomedical devices, photosensors, tactile sensory devices, etc. [31–35].

In terms of tactile sensory devices based on OFETs, liquid crystals (LCs) have been employed as a sensing medium due to their excellent colligative (group) behavior that enables outstanding sensitivity to external stimulations [35]. In particular, planar LC-g(gated)-OFET sensory devices have been invented by using the LC layer, which plays a dual (both gate insulating and sensing) role in device operation, on the drain-source-gate electrodes that are placed on the same plane of substrates [36,37]. Very recently, the

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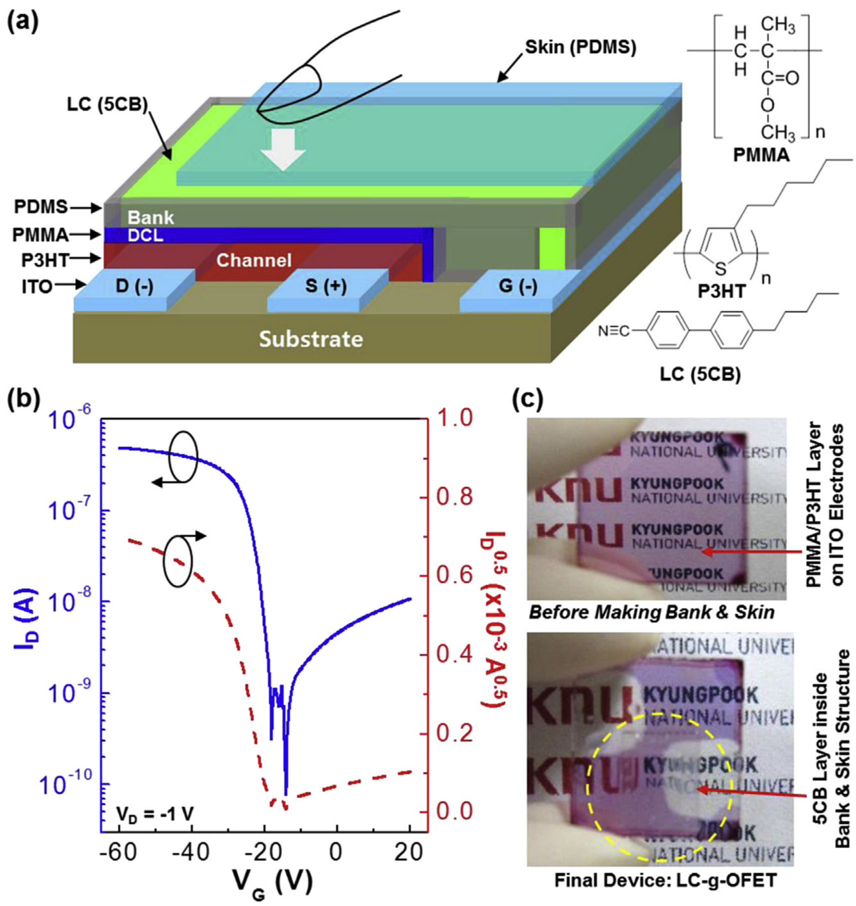

Fig. 1. (a) Illustration for the structure of DCL-LC-g-OFET device and the chemical structure of materials used in this work: 'D', 'S' and 'G' denote drain, source and gate electrodes, respectively. The width and length of ITO electrodes (D, S and G) in the effective zone of devices were 18 μm and 3 mm, respectively. Note that the skin and bank parts, which are made of poly(dimethyl siloxane) (PDMS) film, were partially open in order to observe where the LC layer is. (b) Transfer characteristics of the present DCL-LC-g-OFET device at $V_D = -1$ V (the sweep direction was from $V_G = +20$ V to -60 V). (c) Photographs for the DCL-LC-g-OFET device with (top) and without (bottom) the PDMS bank and skin parts.

intrinsic leakage issue of LC-g-OFET devices, which is induced on the surface of channel layers by the high-k feature of LC molecules, was overcome by inserting a dipole control layer (DCL) [38].

In this work, a direct physical touch has been applied to the LC-g-OFET with DCL, which consists of poly(3-hexylthiophene) (P3HT) channel layer and poly(methyl methacrylate) (PMMA) DCL layer, in order to investigate the possibility as a physical touch sensor in the presence of DCL. A pencil-like load (0.6 g–4.8 g) was employed as a physical touch source, while sensing signals were measured upon touch by human fingers. To protect the active zone that contains P3HT, PMMA, and LC (4-cyano-4'-pentylbiphenyl - 5CB) layers from the external physical touches, poly(dimethylsiloxane) (PDMS) films were introduced as a flexible skin.

2. Experimental section

2.1. Materials and device fabrication

5CB (purity = 98%) and PMMA (weight-average molecular weight = 120 kDa, polydispersity index = 2.2) were supplied from Sigma–Aldrich (USA), while P3HT (weight-average molecular weight = 30 kDa, polydispersity index = 1.7, regioregularity = 97%) was provided from Rieke Metals (USA). The P3HT powder was dissolved in toluene at a solid concentration of 13 mg/ml, while n-butyl acetate was used as a solvent to make the PMMA solution (concentration = 10 mg/ml). To make a planar OFET structure, indium-tin oxide (ITO)-coated glass substrates were subject to a photolithography-etching process. The patterned three ITO electrodes (width = 18 μm and length = 3 mm in the effective zone) were made on the same plane of glass substrates (overall size = 12 mm x 12 mm), which led to the channel length of 15 μm between the source (S) and drain (D) electrodes (see Fig. 1a). After wet cleaning process with acetone and isopropyl alcohol, the patterned ITO-glass substrates were dried before spin-coating the P3HT channel layer. The P3HT layers (thickness = 50 nm) were annealed for 30 min at 120 °C, followed by spin-coating of the PMMA layers (thickness = ~10 nm). The PMMA DCL layers were also annealed for 30 min at 120 °C. In order to prevent a possible leakage current between the source electrode and the gate (G) electrode, the P3HT and PMMA layers were removed from the S-G zone. Next, a PDMS bank (thickness = 10 μm) with a rectangular hole was mounted on the P3HT/PMMA layer to confine the 5CB molecules to the active zone. After placing 5CB inside the rectangular hole in the PDMS bank, another PDMS film without any holes was covered on top of the LC (5CB) layer as a protective skin.

2.2. Measurements

The thickness of polymer layers was measured using a surface profiler (alpha-step 200, Tencor), while the surface of each polymer layer was examined with an optical microscope (SV-55, SOMETECH). The characteristics of DCL-LC-g-OFET devices were