TIPS-Pentacene Organic Field-Effect Transistors Utilizing Poly(p-silsesquioxane) Insulating Layers With Different Phenol Groups

Yuta Nakanishi¹, Hirotake Kaji¹, Koki Tamura², Yutaka Ohmori¹
¹Graduate School of Engineering, Osaka University, 2-1, Yamada-oka,Suita, 565-0871 Osaka, Japan
²Tokyo Ohka Kogyo Co. Ltd., 1590 Tabata Samukawa-Cho, Koza-Gun, Kanagawa 253-0114, Japan
E-mail:ohmori@oled.eei.eng.osaka-u.ac.jp

1. Introduction

Organic field-effect transistors (OFETs) using SiO₂ as gate insulator have been commonly investigated. Polymer gate insulators have attracted much attention owing to their novel properties such as solution-process-based fabrication, smooth surfaces, optical transparency and thermal stability. The electrical characteristics of OFETs also depend on the interface states between the organic active layer and the gate insulator. Thus, the choice of the gate insulator is important. Therefore, poly(p-silsesquioxane) (PSQ) derivatives [1-2] which have ladder-type repeating unit (-Si-O-) were used as a polymeric gate insulator, which contains various phenol-group with a hydroxyl group bonded to a phenyl ring in the side chain of their molecular structures.

P-type conducting 6,13-bis(triisopropyl-silylethynyl) pentacene (TIPS-Pentacene) is one of candidates to realize solution processed p-type transistors with stable and relatively high carrier mobility.

In this study, we investigated the effect of the hydroxyl group of polymer gate insulators on the characteristics of p-type TIPS-Pentacene OFETs using PSQ derivatives.

2. Experimental Procedure

Top- and bottom-contact, bottom-gate-type OFETs were fabricated on a commercially available polished indium tin oxide (ITO) precoated glass substrate. ITO was etched to leave an area of the gate electrode of OFET. The substrate was degreased with solvents in an ultrasonic bath, and cleaned in a UV ozone chamber. Polymer insulators were spun onto an ITO-coated substrate from a propylene glycol monomethyl ether acetate (PGMEA) solution, and baked in ambient atmosphere. Figure 1 shows the molecular structures of (a) poly(p-hydroxybenzylsilsesquioxane) (all-OH), (b)poly(p-hydroxybenzylsilsesquioxane-phenylsilsesquioxane) (part-OH), and (c) poly(p-ethoxyethylsilsesquioxane-phenylsilsesquioxane) (part-Ethoxyethyl) used as polymer gate insulators in this study. The ratio of the hydroxyl group contained in the polymer insulator decreases in the order of all-OH, part-OH and part-Ethoxyethyl. The polymer insulators were baked at 200°C for 20 min after spinning in order to remove a PGMEA solvent from the insulator layer. The typical thicknesses of polymer insulators were approximately 400 nm. As an organic semiconductor material, TIPS-Pentacene was drop-casted from chlorobenzene (5mg/ml) solution, and baked at 80°C in ambient atmosphere. A typical thickness of the TIPS-Pentacene layer was approximately a few hundred nm. As a source/drain electrode, Au or Ag was vacuum-evaporated with a shadow mask at a background pressure of about 10⁻⁴ Pa. The thicknesses of Au and Ag were 30 nm. The channel length and width were 0.1 and 2 mm, respectively.

All measurements of electrical characteristics of OFETs were carried out in a vacuum chamber at a background pressure of about 10⁻⁴ Pa.

![Fig. 1 Molecular structures of polymer insulators used in this study.](image1)

![Fig. 2 Output characteristics of a top-contact OFET with part-OH as gate insulator.](image2)

3. Results and Discussion

Figure 2 shows typical output characteristic of an top-contact OFET with part-OH as the gate insulator. The saturation characteristic of each device was typical for p-type OFET working in the accumulation mode. The drain–source current increased superlinearly at lower drain–source voltages. These superlinear currents result from the relatively large contact resistance owing to the thick active layer between the polymer insulators and Au source/drain electrodes.
Figure 3 shows the source/drain current ($I_{DS}$) versus gate voltage ($V_{GS}$) at a source-drain voltage ($V_{DS}$) of -50V. The threshold voltage and field-effect mobility were estimated from the form of the square root of $I_{DS}$ versus $V_{GS}$ plotting the saturated current at -50V. The hole mobilities of OFETs were estimated as order of 0.1 cm²/Vs. These values are the almost same as that of an OFET utilizing Pentacene as an active layer. The electrical parameters were summarized in Table 1. From this table, the off-current of OFET with all-OH, which had only hydroxyl group in all the side chains, was larger than those with part-OH and part-Ethoxyethyl owing to the dipole of hydroxyl-group.

Next, we investigated the characteristics of the bottom-contact OFETs for the decrease of contact resistance owing to the top-contact structure. For bottom-contact OFETs, the electrical characteristics of OFETs depend on the interface state between the organic active layer and the source/drain electrodes. Therefore, surface treatment utilizing self-assembly monolayer (SAM) could be an effective means of improving the performance of OFETs. In order to decrease the damage of gate insulator within the SAM treatment, we employed bottom-contact OFET utilizing the photocrosslinked-PSQ. In addition, for utilizing the photocrosslinked PSQ, the ratio of the hydroxyl group contained in the gate insulator decreased. In order to improve the carrier injection between Ag source/drain electrodes and organic layer, a SAM solution (Lisicon M001) purchased from Merk Co. was treated on Ag source/drain electrodes.

Figure 4 shows typical output characteristic of an OFET with 120nm-thick photocrosslinked-PSQ as gate insulator. For a bottom-contact OFET, the drain–source current increased linearly at lower drain–source voltages owing to the improvement of injection. The saturation characteristic was typical for p-type OFET. The OFET driven at operating voltages of 10V was achieved by using thin gate insulators. The threshold voltage and field-effect mobility were estimated from the form of the square root of $I_{DS}$ versus $V_{GS}$ plotting the saturated current at -8V. The threshold voltage and the hole mobility of OFET were estimated as -2V and 0.1 cm²/Vs, respectively. The hole mobility of bottom-contact OFET with low voltage operation was the almost same as those of top-contact OFETs.

Acknowledgement
Part of this work was supported by Grant-in-Aid for Scientific Research, from the Ministry of Education, Culture, Sports, Science and Technology, Japan. This research was also partially supported financially by a grant for the Osaka University Global COE Program, “Center for Electronic Devices Innovation” and a Grant in Aid of Special Coordination Funds for Promoting Science and Technology.

References