A 6,13-bis(Triisopropylsilylethynyl) Pentacene Thin-Film Transistor Using a Spun-On Inorganic Gate-Dielectric

Jae-Hong Kwon, *Student Member, IEEE*, Jung-Hoon Seo, *Student Member, IEEE*, Sang-Il Shin, Kyung-Hwan Kim, Dong Hoon Choi, In Byeong Kang, Hochul Kang, and Byeong-Kwon Ju, *Member, IEEE*

***Abstract*—We present the latest results of the use of soluble materials such as organic semiconductors (OSCs) or gate-dielectrics for simplified processing of organic thin-film transistors (OTFTs). In this paper, we described our fabrication of a solution-processed OTFT with 6,13-bis(Triisopropylsilylethynyl) pentacene (TIPS-pentacene) as the OSC and siloxane-based spin-on glass (SOG) as the inorganic gate-dielectric. Also, synthesized TIPS-pentacene and SOG were examined for use as the OSC and gate-dielectric in an OTFT. From electrical measurements, we obtained device performance characteristics such as charge carrier mobility, threshold voltage, current ON/OFF ratio, and subthreshold swing, which were 6.48×10^{-3} cm^2/V · s, −13 V, ∼100, and 1.83 V/dec, respectively.**

***Index Terms*—6,13-bis(Triisopropylsilylethynyl) pentacene (TIPS-pentacene), organic electronics, organic thin-film transistor (OTFT), spin-on glass.**

I. Introduction

THE PERFORMANCE of organic thin-film transistors (OTFTs) has improved remarkably during the last decade. Thus, it is at least the same as that of a hydrogenated amorphous silicon (α-Si:H) thin-film transistor (TFT), which is currently used for the manufacturing of TFT-liquid crystal displays. However, its severe insolubility renders it useless for solution-based fabrication of electronic devices. Solution-based processing is the key to enabling ultralow-cost circuit fabrication. This processing eliminates the need for lithography, subtractive processing, and vacuum-based film deposition. Recently, there has been great interest in the development of printed organic electronics technologies since these technologies allow the use of spin coating, drop casting, ink jet printing, spray coating, nanoimprinting, or the screen printing process [1]–[6]. These technologies are expected to be used in low-cost, flexible displays and disposable electronics applications. As a consequence, extensive research by many groups has been actively carried out to improve the charge carrier mobility and the current modulation.

The morphology of the dielectric surface onto which the organic semiconductor (OSC) layer is formed is an important factor in the device performance of OTFTs. It has been reported [7], [8] that a rougher surface leads to more defects and voids that can act as traps at OSC–dielectric interface. The surface roughness also affects the ordering of OSC molecules during an active-layer formation [9], [10]. Therefore, OTFT with low surface roughness film exhibits good electric performance.

In this paper, we utilize a very smooth surface roughness film, spin-coatable inorganic dielectric, less sensitive to moisture, and a siloxane-based spin-on-glass (SOG) as gate dielectric for OTFT. Also, we present the characterization of synthesized 6,13-bis(Triisopropylsilylethynyl) pentacene (TIPS-pentacene) as a p-type OSC. We discuss their applications in solution-process-based OTFTs. We obtained the thermal properties, optical properties, and device performances using both TIPS-pentacene and SOG as results. This paper may help us to understand the structural relationships of the materials. It may provide a useful way for the rational design of transistor materials or their applications.

II. Material and Device Fabrication

Functionalized pentacene, TIPS-pentacene, leads to a highly soluble and oxidatively stable OSC as a hole transport channel designed to exhibit enhanced π-stacking interactions. It is easily prepared in near quantitative yield in a one-pot reaction from 6,13-pentacenequinone [7]. TIPS-pentacene [see Fig. 1(a)], synthesized as described elsewhere [11], [12], was synthesized to address precisely these limitations. On one hand, the TIPS side groups make TIPS-pentacene soluble in common organic solvents; on the other hand, these bulky groups also help to disrupt the face-to-edge herringbone packing pattern and to form a regular columnar stacking between the acene planes [11]–[13]. For a solution processable gate dielectric, we utilized a siloxane-based SOG (Honeywell 512B, dielectric constant $= 3.1 \pm 0.1$) that was composed primarily of siloxane that contained CH_3 (15% organic content) groups bonded to Si atoms in the Si–O backbone, as illustrated in Fig. 1(c). Unlike polymer dielectric materials, an inorganic dielectric, SOG would not have the moisture and hysteresis problems of a polymer dielectric [14].

Manuscript received June 8, 2007; revised October 22, 2007. This work was supported in part by the Industrial-Educational Cooperation Program between Korea University and LG. Philips LCD, in part by the National Research Laboratory under Grant NRL, R0 A-2007-000-20111-0 Program of the Ministry of Science and Technology (Korea Science and Engineering Foundation), and in part by the second stage of the Brain Korea 21 Project in 2007 (Korea Research Foundation). The review of this paper was arranged by Editor J. Kanicki.

J.-H. Kwon, J.-H. Seo, S.-I. Shin, and B.-K. Ju are with the Display and Nanosystem Laboratory, College of Engineering, Korea University, Seoul 136-701, Korea (e-mail: jhkwon@korea.ac.kr; jh-seo@hotmail.com; lieve21@korea.ac.kr; bkju@korea.ac.kr).

K.-H. Kim and D. H. Choi are with the Department of Chemistry, Korea University, Seoul 136-701, Korea (k2h1306@korea.ac.kr; dhchoi8803@korea.ac.kr).

I. B. Kang and H. Kang are with the LG. Philips LCD R&D Center, Kyongki-do 431-080, Korea (e-mail: ibkang@lgphilips-lcd.com; mujigae7@lgphilips-lcd.com).

Color versions of one or more of the figures in this paper are available online at http://ieeexplore.ieee.org.

Digital Object Identifier 10.1109/TED.2007.913007

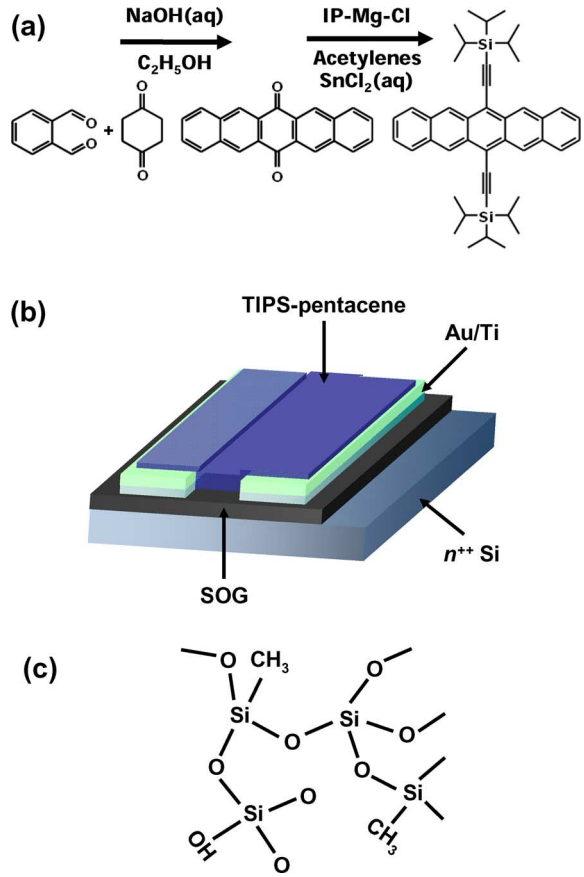

Fig. 1. (a) Chemical structure of 6,13-bis(Triisopropylsilylethynyl) pentacene. (b) Schematic of the inverted staggered OTFT structure on a highly doped Si wafer with a gate electrode. (c) Structure of Accuglass 512B (spin-on glass) composed mainly of siloxane.

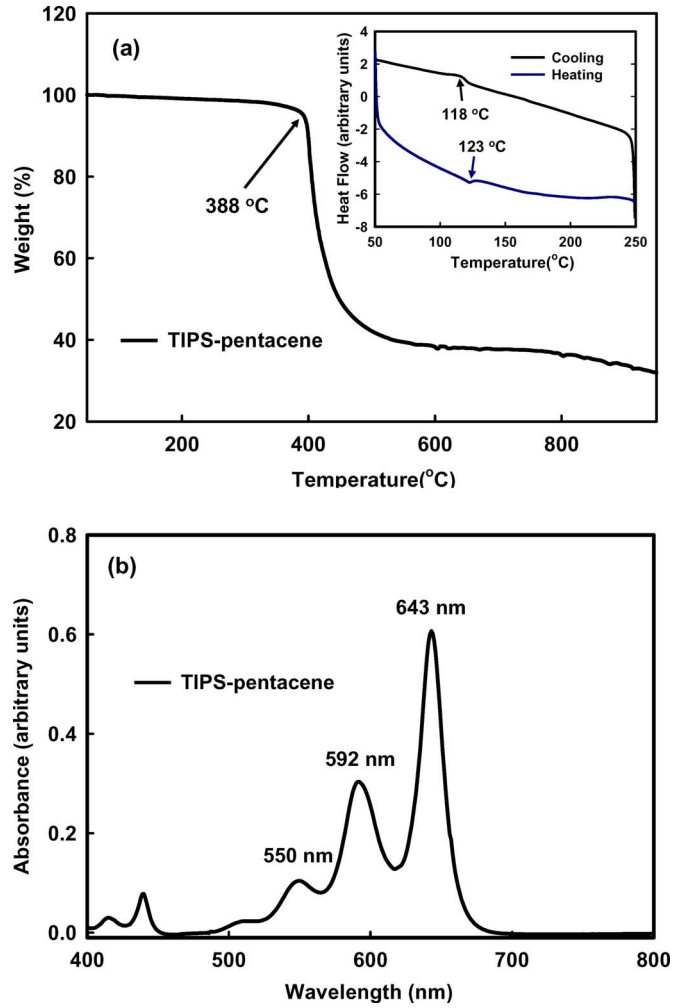

Fig. 2. (a) TGA plots with a heating rate of 10 °C /min under nitrogen. The inset shows the DSC traces with a heating (cooling) rate of 10 (−10) °C/min under a nitrogen flow. (b) Optical absorption (UV-Vis) spectra of TIPS-pentacene in chloroform.

The schematic structure of a TIPS-pentacene/SOG-based OTFT is shown in Fig. 1(b). The devices were made by using a heavily doped n-type Si wafer, with an optimized SOG [14], which functioned as the gate electrode and the gate insulator, respectively. The SOG was spin-coated on the HF-treated Si surface at a spin rate of 4000 r/min for 20 s, baked successively at 80 and 250 °C for 1 min each in air, and finally, cured at 450 °C at 1.0 $\mathrm{L \cdot min^{-1}}$ N_2 flow. The details about the SOG/Si surface were described in the literature [15]–[17]. Gold (Au, 70 nm thickness) source/drain contacts including titanium (Ti, 30 nm thickness), which acted as an adhesion layer, were deposited by electrobeam evaporation. Also, a shadow mask was used to define the source and drain electrodes. The channel width (W) and length (L) were 500 and 20 μm, respectively. Next, the TIPS-pentacene film was deposited by a drop casting. Finally, the coated TIPS-pentacene-based device was annealed using an oven at 110 °C for 30 min. After the device fabrication, the transistor characteristics were measured using Keithley SCS/4200 in ambient air.

III. Result and Discussion

The thermal properties of TIPS-pentacene were investigated using thermogravimetric analysis (TGA) (TA Instrument 2050) and differential scanning calorimetry (DSC) (Mettler Toledo DSC821e analyzer), as shown in Fig. 2(a). These techniques were used to characterize the thermal transitions in polymers. TGA is a simple analytical technique that measures the weight retention of a material as a function of temperature. The TGA data for TIPS-pentacene revealed inflections at 388 °C that suggested that a decomposition process occurred. In addition, a significant decomposition-related residue was observed at ∼498 °C, as shown in Fig. 2(a). By substituting the bulky groups at the 6 and 13 positions of pentacene, edge-to-face interactions are inhibited; it forms molecular crystals with a slip-stacked structure, which resulted in a decomposition process at high temperature. When a high-temperature DCS was run from 50 to 250 °C, two peaks were observed, as shown in the inset of Fig. 2(a). The endothermic peak (heating line) at 123 °C corresponded to the melting of the compound. The exothermic peak (cooling line) at 118 °C indicated a structural phase transition. Fig. 2(b) depicts the optical absorption [ultraviolet-visible (UV-Vis) spectrometry, HP 8453, PDA, type $\lambda = 190$–1100 nm] spectra of the solution of TIPS-pentacene in chloroform. The

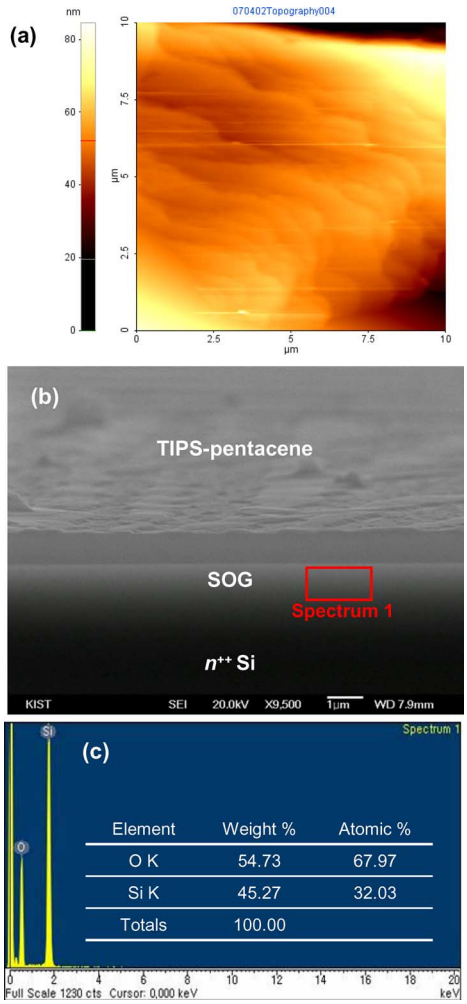

Fig. 3. (a) $10 \times 10\ \mu m^2$ SPM image of the TIPS-pentacene film on SOG. (b) FE-SEM micrograph (with an apparent viewing angle of 12°) of the same TIPS-pentacene film presented in Fig. 1(a). (c) EDX of a siloxane-based spin-on glass film showing a stoichiometric elemental percentage analysis.

absorption maximum peak was at 643 nm with a few absorption peaks between 400 and 600 nm that matched the absorption spectrum reported for TIPS-pentacene in the tetrahydrofuran solution [18]. The functionalization of TIPS-pentacene with electron-rich substituents resulted in oxidatively stable and highly soluble organic active materials that can be engineered to preserve the close π-stacking and increased orbital overlap [19].

Fig. 3(b) shows a cross-sectional field-emission scanning electron microscope (FE-SEM) image presented in Fig. 1(c), which is the image of the TIPS-pentacene layer on the precoated SOG layer on the n^{++} Si substrate. The thicknesses of the TIPS-pentacene and SOG layers were about 800 and 750 nm, respectively. Fig. 3(a) shows the scanning probe microscopy (SPM, XE-100 system) image of TIPS-pentacene coated onto the SOG/Si substrate. The bright area in the image was interpreted as increasing the film thickness in that direction. Fig. 3(a) is a topographic image of the OCS film formed by drop casting from a 2 wt% solution of TIPS-pentacene in toluene. The image demonstrated continuous films, but also showed what appeared to be molecular steps with the rms roughness of 9.835 nm at 110 °C. The elemental energy dispersive X-ray (EDX, Horiba EX-200) analysis [Fig. 3(c)] was carried out only for siloxane-based SOG. The average atomic percentage ratio of O:Si was 67.97:32.03 [inset table of Fig. 3(c)] showing that the ratio of O to Si in the silicon-oxide formed by the room-temperature reaction was 2.12. This was about the same as that of thermally grown SiO_2 (O/Si ratio of standard SiO_2: 2) [20]. Also, it was known [21] that a low surface roughness was necessary for high mobility. The very smooth surface (rms roughness = 0.508 nm while rms roughness of thermally grown SiO_2 = 1.08 nm, not shown here) that the SOG provided must have contributed to the relatively high mobility obtained. It can be seen that a clear interface exists between the gate-dielectric and the OSC film, as shown in Fig. 3(b). If the dielectric film has poor surface roughness, then this roughness leads to valleys in the channel region. These valleys may act as carrier traps with a number of scatterings [22]. To further investigate the device performance, surface properties of dielectric layers were characterized by advancing the water-contact angle measurement (not shown here). SOG was rather hydrophobic surface with a water-contact angle of ~86° while thermal grown SiO_2, relatively hydrophilic surface with a water contact angle of ~42° was measured. From these results, it is believed that the relatively large water-contact angle of SOG with nonploar character is attributable to higher density of methyl (CH_3) groups and a near absence of hydroxyl (OH) groups on the surface. Therefore, TIPS-pentacene/SOG-based OTFT has higher performance than that of TIPS-pentacene/SiO_2-based OTFT because of relatively less hydroxyl bindings in SOG dielectric surface related to nearly no hysteresis of device [23]. Fig. 4 shows the electrical characteristics of drop-casted TIPS-pentacene on thermally grown SiO_2/Si wafer. From the electrical output [Fig. 4(a)] and transfer [Fig. 4(b)] curve, TIPS-pentacene/SiO_2-based OTFT had an extracted mobility of up to $4.91 \times 10^{-5}\ cm^2/V \cdot s$, threshold voltage of 11 V, current ON/OFF ratio of ~100, and subthreshold swing of 3.07 V/dec. All electrical measurements were performed in air ambient at room temperature and in ambient light condition.

The output and transfer characteristics are shown in Fig. 5 for a TIPS-pentacene thin-film transistor with siloxane-based SOG as an inorganic gate dielectric. The high work function of Au was expected to improve the injection of holes into the OSCs. The Au contacts sometimes produced low mobilities ($<10^{-4}\ cm^2/V \cdot s$) which improved to about $6.48 \times 10^{-3}\ cm^2/V \cdot s$ following annealing at a temperature of 110 °C. Fig. 5(a) shows drain-current (I_D) versus drain-voltage (V_D) of the TIPS-pentacene/SOG-based OTFT as the source–drain electrodes at different gate voltage (V_G). The curve was typical for p-type OTFT working in an accumulation mode. The positive current near the 0 V drain bias (V_D), increasing with V_G, was the result of the leakage current through the gate-dielectric layer between the source–drain and gate electrodes. To improve the device contact characteristics, the treatment of the interface between the OSC and gate-dielectric layer using a self-assembled monolayer was studied by other groups [24]. The corresponding plots of I_D and $\sqrt{I_D}$ versus V_G for the device are shown in Fig. 5(b). The device had a subthreshold swing of 1.83 V per decade,

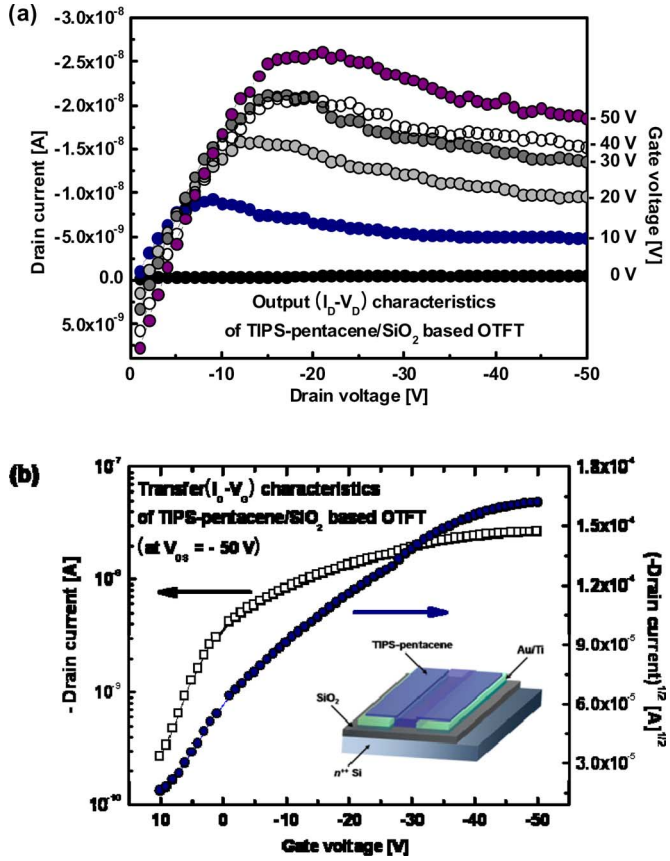

Fig. 4. Current–voltage characteristics of a TIPS-pentacene/SiO_2-based OTFT. (a) Drain current (I_D) versus the drain voltage (V_D) characteristic curve where the gate voltage (V_G) varies between 0 and -50 V in steps of -10 V. (b) Log I_D and square root of drain current ($\sqrt{I_D}$) as a function of V_G (from $+10$ to 50 V) at drain to source voltage (V_{DS}). The inset shows the schematic of the inverted staggered the TIPS-pentacene/SiO_2-based OTFT structure (W/L = 500 μm/20 μm) on a highly doped Si wafer with a gate electrode. The SiO_2, as gate-dielectric, was thermally grown to a thickness of 300 nm. The drop-casted OSC-based device was annealed using an oven at 110 °C for 30 min.

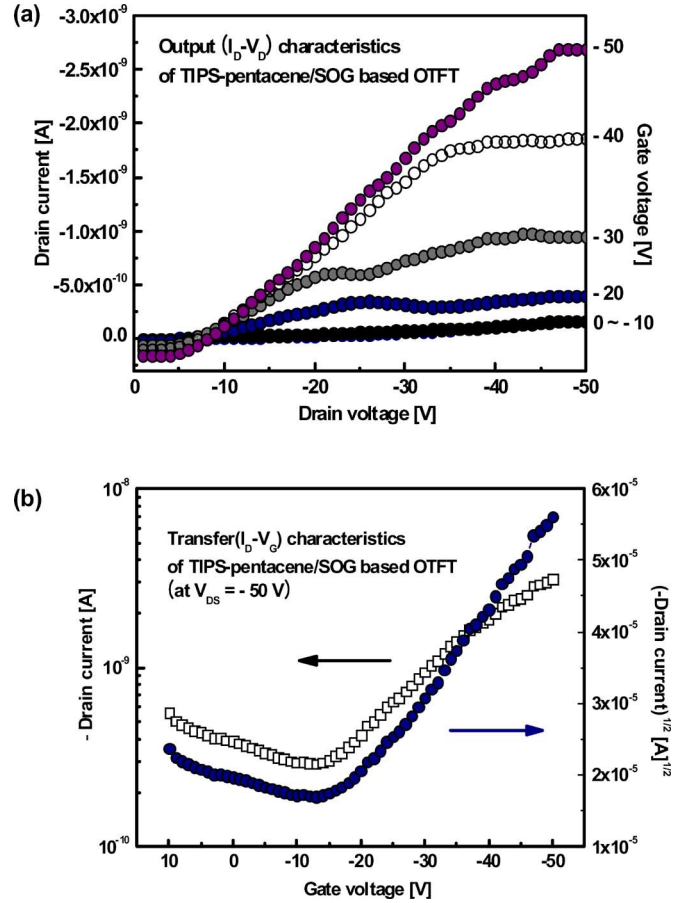

Fig. 5. Current–voltage characteristics of a TIPS-pentacene/SOG-based OTFT. (a) I_D versus the V_D characteristic curve where the V_G varies between 0 and -50 V in steps of -10 V. The increasing deviations from zero current at zero drain-source voltage with higher gate voltages are caused by leakage through the dielectric. (b) Log I_D and $\sqrt{I_D}$ versus V_G curve that results when the gate voltage is scanned from $+10$ to -50 V.

an extracted mobility of up to 6.48×10^{-3} cm^2/V · s, and had a threshold voltage of -13 V [from Fig. 5(b)]. However, the current ON/OFF ratio was relatively small ($\sim$100). The current ON/OFF ratio was limited by the OFF current (2.9×10^{-10} A) that was extremely low in our device. This was related to a high material purity without unintentional doping by charge carriers. The distribution of traps was considered to be an important explanation for the high current ON/OFF ratio of OTFTs assumed on amorphous molecular materials [25]. However, our device has lower performance than that of the TIPS-pentacene-based OTFT with carrier mobility >1 cm^2/V · s fabricated by other research groups [26], [27]. Because the carrier channel in which the electronic charges were transported in the device was formed in close proximity to the interface, the properties of the OSC/gate-dielectric interface were of critical importance. Hence, the treatment of the interface between the OSC and gate-dielectric layer using dry or wet cleaning techniques and surface modification of gate-dielectric using self-assembled monolayer were studied by other groups [26]–[30] to improve the characteristics of the OTFTs.

IV. Conclusion

We have reported a solution-processed OTFT consisting of TIPS-pentacene as an OSC and SOG as a gate-dielectric. Although the device characteristics described here were not well optimized and contacts appeared to limit device performance, our work provided advantages in the areas of solubility, processability, and tunability for organic electronics applications through soluble materials. This paper has provided a possible path to low-cost and large-area organic electronics processing.

Acknowledgment

The authors would like to thank J.-W. Jeong of Nano Device Research Center, Korea Institute of Science and Technology, Seoul, Korea, for scanning probe microscopy (SPM) measurement.

References

[1] J. H. Kwon, J. H. Seo, H. C. Kang, D. H. Choi, and B. K. Ju, "p-type semiconducting α,ω-dihexylsexithiophene for an organic thin film transistor," *J. Appl. Phys.*, vol. 101, no. 6, pp. 0645021–0645024, Mar. 2007.

[2] T. Someya, Y. Kato, S. Iba, H Kawaguchi, and T. Sakurai, "Integration of organic FETs with organic photodiodes for a large area, flexible, and lightweight sheet image scanners," *IEEE Trans. Electron Devices*, vol. 52, no. 11, pp. 2502–2511, Nov. 2005.

[3] E. Huitema, G. Gelinck, B. Van Der Putten, E. Cantatore, K. Kuijk, K. Hart, and D. de Leeuw, "Plastic transistors used as pixel switches in AMLCD," *J. SID*, vol. 10, no. 3, pp. 195–202, Sep. 2002.

[4] J. H. Kwon, K. S. Lee, Y. H. Lee, and B. K. Ju, "Single wall carbon nanotube-based pH sensor fabricated by spray method," *Electrochem. Solid State Lett.*, vol. 9, no. 9, pp. H-85–H-87, Jun. 2006.

[5] A. C. Arias, S. E. Ready, R. Lujan, W. S. Wong, K. E. Paul, A. Salleo, M. L. Chabinyc, R. B. Apte, R. A. Street, Y. Wu, P. Liu, and B. Ong, "All jet-printed polymer thin-film transistor active-matrix backplanes," *Appl. Phys. Lett.*, vol. 85, no. 15, pp. 3304–3306, Oct. 2004.

[6] J. H. Kwon, S. H. Lee, and B. K. Ju, "Screen-printed multi-crystalline silicon solar cells with porous silicon antireflective layer formed by electrochemical etching," *J. Appl. Phys.*, vol. 101, no. 9, pp. 1045151–1045154, May 2007.

[7] I. Kymissis, C. D. Dimitrakopoulos, and S. Purushothaman, "High-performance bottom electrode organic thin-film transistors," *IEEE Trans. Electron Devices*, vol. 48, no. 6, pp. 1060–1064, Jun. 2001.

[8] D. J. Gundlach, L. Jia, and T. N. Jackson, "Pentacene TFT with improved linear region characteristics using chemically modified source and drain electrodes," *IEEE Electron Device Lett.*, vol. 22, no. 12, pp. 571–573, Dec. 2001.

[9] J. H. Seo, J. H. Kwon, S. I. Shin, K. S. Suh, and B. K. Ju, "Organic thin film transistors with polyvinyl alcohol treated dielectric surface," *Semicond. Sci. Technol.*, vol. 22, no. 9, pp. 1039–1043, Aug. 2007.

[10] H. Sirringhaus, P. J. Brown, R. H. Friend, M. M. Nielsen, K. Bechgaard, B. M. W. Langeveld-Voss, A. J. H. Spiering, R. A. J. Janssen, E. W. Meijer, P. Herwig, and D. M. de Leeuw, "Two-dimensional charge transport in self-organized, high-mobility conjugated polymers," *Nature*, vol. 401, pp. 685–688, Oct. 1999.

[11] J. E. Anthony, J. S. Brooks, D. L. Eaton, and S. R. Parkin, "Functionalized pentacene: Improved electronic properties from control of solid-state order," *J. Amer. Chem. Soc.*, vol. 123, no. 38, pp. 9482–9483, Sep. 2001.

[12] J. E. Anthony, D. L. Eaton, and S. R. Parkin, "A road map to stable, soluble, easily crystallized pentacene derivatives," *Org. Lett.*, vol. 4, no. 1, pp. 15–18, Sep. 2002.

[13] C. D. Sheraw, T. N. Jackson, D. L. Eaton, and J. E. Anthony, "Functionalized pentacene active layer organic thin-film transistors," *Adv. Mater.*, vol. 15, no. 23, pp. 2009–2011, Dec. 2003.

[14] K. Han, S. Y. Park, M. J. Kim, and H. H. Lee, "Spin-coatable inorganic gate dielectric for organic thin-film transistors," *Appl. Phys. Lett.*, vol. 87, pp. 2535021–2535023, Dec. 2005.

[15] M. M. Rahman, R. Tero, and T. Urisu, "Shrinking of spin-on-glass films induced by synchrotron radiation and its application to three-dimensional microfabrications," *Jpn. J. Appl. Phys.*, vol. 43, no. 6B, pp. 3941–3944, Jun. 2004.

[16] Z. Bao, V. Kuck, J. A. Rogers, and M. A. Paczkowski, "Silsesquioxane resins as high-performance solution processible dielectric materials for organic transistor applications," *Adv. Funct. Mater.*, vol. 12, no. 8, pp. 526–531, Aug. 2002.

[17] L. L. Chua, P. H. Ho, H. Sirringhaus, and R. FriendHigh, "High-stability ultrathin spin-on benzocyclobutene gate dielectric for polymer field-effect transistors," *Appl. Phys. Lett.*, vol. 84, no. 17, pp. 3400–3402, Feb. 2004.

[18] A. Maliakal, K. Raghavachari, H. Katz, E. Chandross, and T. Siegrist, "Photochemical stability of pentacene and a substituted pentacene in solution and in thin films," *Chem. Mater.*, vol. 16, no. 24, pp. 4980–4986, Aug. 2004.

[19] M. M. Payne, J. H. Delcamp, S. R. Parkin, and J. E. Anthony, "Robust, soluble pentacene ethers," *Org. Lett.*, vol. 6, no. 10, pp. 1609–1612, Mar. 2004.

[20] K. Hinode, K. Takeda, and S. Kondo, "Abnormal room-temperature oxidation of silicon in the presence of copper," *J. Vac. Sci. Technol., A*, vol. 20, no. 5, pp. 1653–1658, Jun. 2002.

[21] H. Klauk, M. Halik, U. Zschieschang, G. Schmid, W. Radlik, and W. Weber, "High-mobility polymer gate dielectric pentacene thin film transistors," *J. Appl. Phys.*, vol. 92, no. 9, pp. 5259–5263, Nov. 2002.

[22] D. K. Hwang, W. Choi, J.-M. Choi, K. Lee, J. H. Park, E. Kim, J. H. Kim, and S. Im, "Systematic studies on low-voltage pentacene thin film transistors with low-k polymer/high-k oxide bilayer gate dielectic," *J. Electrochem. Soc.*, vol. 154, no. 11, pp. H933–H938, Sep. 2007.

[23] S. C. Lim, S. H. Kim, J. B. Koo, J. H. Lee, C. H. Ku, Y. S. Yang, and T. Zyung, "Hysteresis of pentacene thin-film transistors and inverters with cross-linked poly(4-vinylphenol) gate dielectrics," *Appl. Phys. Lett.*, vol. 90, pp. 1735121–1735123, Oct. 2007.

[24] C. S. Kim, S. J. Jo, S. W. Lee, W. J. Kim, H. K. Baik, S. J. Lee, D. K. Hwang, and S. Im, "High-k and low-k nanocomposite gate dielectrics for low voltage organic thin film transistors," *Appl. Phys. Lett.*, vol. 88, pp. 2435151–2435153, Jun. 2006.

[25] J. Ghim, K.-J. Baeg, Y.-Y. Noh, S.-J. Kang, J. Jo, D.-Y. Kim, S. Cho, J. Yuen, K. Lee, and A. J. Heeger, "Perfluorocyclobutane containing polymeric gate dielectric for organic thin film transistors with high on/off ratio," *Appl. Phys. Lett.*, vol. 89, pp. 2025161–2025163, Nov. 2006.

[26] S. K. Park, T. N. Jackson, J. E. Anthony, and D. A. Mourey, "High mobility solution processed 6,13-bis(Triisopropyl-silylethynyl) pentacene organic thin film transistors," *Appl. Phys. Lett.*, vol. 91, pp. 0635141–0635143, Aug. 2007.

[27] D. H. Kim, D. Y. Lee, H. S. Lee, W. H. Lee, Y. H. Kim, J. I. Han, and K. Cho, "High-mobility organic transistors based on single-crystalline microribbons of triisopropylsilylethynyl pentacene via solution-phase self-assembly," *Adv. Mater.*, vol. 19, no. 5, pp. 678–682, Feb. 2007.

[28] W. H. Lee, D. H. Kim, Y. Jang, J. H. Cho, M. Hwang, Y. D. Park, Y. H. Kim, J. I. Han, and K. Cho, "Solution-processable pentacene microcrystal arrays for high performance organic field-effect transistors," *Appl. Phys. Lett.*, vol. 90, pp. 132106-1–132106-3, Mar. 2007.

[29] C. C. Kuo, "High performance small-molecule organic thin film transistors," Ph.D. dissertation, Pennsylvania State Univ., State Ccollege, PA, Dec. 2005.

[30] S. K. Park, J. E. Anthony, and T. N. Jackson, "Solution-processed TIPS-pentacene organic thin-film-transistor circuits," *IEEE Electron Device Lett.*, vol. 28, no. 10, pp. 877–879, Oct. 2007.

Jae-Hong Kwon received the B.S. and M.S. degrees in electronics engineering from Sejong University, Seoul, Korea, in 2003 and 2005, respectively. He is currently working toward the Ph.D. degree at Korea University, Seoul, Korea.

During 2003, he was an Intern Researcher with the Corporate R&D Center, Samsung SDI Company, Ltd., Korea. Since 2005, he has been a Researcher in the Semiconductor Research Center, Korea University. Since 2006, he has been an Electronics and Electrical Engineer at Korea University . His current research interests include flexible printed electronics (circuitry, memory, display, sensor) and silicon solar cell.

Jung-Hoon Seo received the B.S. degree in school of electrical engineering from Korea University, Seoul, Korea, in 2006. From 2006, he is working toward the M.S. degree in electronics and electrical engineering, Korea University, Seoul, Korea.

His current research interests include improvement of electrical characteristics of organic electronics such as organic thin-film transistors and organic memory devices.

Sang-Il Shin received the B.S. degree in electrical engineering from Korea University, Seoul, South Korea, in 2007. From 2007, he is currently working toward the M.S. degree in electronics and electrical engineering at Korea University, Seoul, Korea.

His current research interests include soluble-processing fabrication of organic thin-film transistors and their flexible applications.

Kyung-Hwan Kim received the B.S. degree in applied chemistry from the Department of Applied Chemistry, Konkuk University, Chungju, Korea, in 2005, the M.S. degree in chemistry in 2007 from Korea University, Seoul, where he is currently working toward the Ph.D. degree in polymer chemistry.

His current research interests include the materials for organic thin-film transistors.

Dong Hoon Choi received the B.S. and M.S. degrees from the Department of Chemistry and Molecular Engineering, Seoul National University, Seoul, Korea, in 1984 and 1986, respectively, and the Ph.D. degree from the Department of Macromolecular Science and Engineering, University of Michigan, Ann Arbor, in 1991.

From 1991 to 1992, he was a Postdoctoral Research Fellow at the State University of New York, Buffalo. From 1995 to 2005, he was an Associate Professor at Kyung Hee University, Seoul. Since 2005, he has been with the Department of Chemistry, Korea University, Seoul, where he is currently a Professor. His current research interests include the materials for organic light-emitting diodes (OLEDs), organic thin-film transistors (OTFTs), and organic photovoltaic (solar cell) devices.

In Byeong Kang received the M.S. degree from Hanyang University, Seoul, South Korea, in 1991, and the Ph.D. degree from the University of South Australia, South Australia, Australia, in 1997, both in electrical engineering, and since 2002, the M.B.A. and M.S. degrees from Helsinki University, Helsinki, Finland, in 2004.

In 1991, he joined the LG Electronics Research Laboratory in Anyang, and in 1999, was transferred to LG. Philips LCD R&D Center, Kyongki-do, Korea, where he was a Vice President in 2006, and since 2007, he has been an LCD Laboratory Chief.

Hochul Kang received the M.S. and Ph.D. degrees in electrical engineering from Korea University, Seoul, Korea, in 1995 and 2003, respectively.

In 1994, he spent one year as a Visiting Student in Tokyo Institute of Technology, Tokyo, Japan. Between 1995 and 1998, he joined Hyundai Electronics Memory Laboratory, Korea, as a Flash Memory Device Engineer. From 2000 to 2003, he was a Visiting Scholar at the University of Illinois, Urbana-Champaign. Since 2003, he has been a Chief Research Engineer with the LG.Philips LCD R&D Center, Kyongki-do, Korea. His current research interests include polycrystalline silicon thin-film transistor design and fabrication for application to displays, organic thin-film transistor design and fabrication for application to organic electronics, and process integration of thin-film transistors for flat-panel displays.

Byeong-Kwon Ju (M'00) received the M.S. degree in electronic engineering from the University of Seoul, Seoul, Korea, in 1988, and the Ph.D. degree in semiconductor engineering from Korea University, Seoul, in 1995.

In 1988, he joined Korea Institute of Science and Technology (KIST), Seoul, as a Principal Research Scientist, and was engaged in the development of mainly silicon micromachining and microsensors. In 1996, he was a Visiting Research Fellow with the Microelectronics Centre, University of South Australia, South Australia, Australia. Since 2005, he has been an Associate Professor with Korea University, Seoul. He is the author or coauthor of more than 240 journal articles. His current research interests include flexible electronics [organic light-emitting diode (OLED) and organic thin-film transistor (OTFT)], field-emission device, microelectromechanical systems (MEMS) (Bio and RF), and carbon nanotube-based nano systems.

Prof. Ju is a member of the Society for Information Display (SID), the Korea Institute of Electrical Engineering (KIEE), and the Korea Sensor Society.