

Nanocomposite Gate Dielectrics with BST nanoparticles for Organic Thin Film Transistors

Introduction

There has been great interest in thin-film transistors made of organic compounds, since organic compounds, since organic thin-film transistors (OTFTs) have many unique advantages, such as light weight, flexibility, low cost fabrication, and solution processability.

However, traditional OTFTs often suffer from high operating voltage due to the low charge carrier mobility of organic semiconductors. Hence, for the applications that require high current output, such as switching of organic light emitting diode, OTFTs are still not the suitable candidate. Since the field-induced current is proportional to the field-induced charge density and carrier mobility, one way to overcome this problem is to use high dielectric constant gate insulators, which can enhance the field-induced carrier density. However, most high dielectric constant materials used for OTFTs so far are based on ceramics and hence are usually brittle and expensive to prepare. Therefore, it is necessary to develop a cheap and easy way (e.g. solution-processable method) to fabricate gate insulators with a high dielectric constant.

Experimental

In order to fabricate solution-processable gate dielectric layer with high dielectric constant for organic thin film transistors (OTFTs), we have prepared the nanocomposite films, which consist of cross-linked poly-4-vinyl phenol (PVP) and (Ba,Sr)TiO₃ (Barium strontium titanate; BST) nanoparticles as follows:

Nano-sized BST particles were prepared by flame spray pyrolysis method. This method allows to making nanoparticles without aggregation during the fabrication process. The particle size was around (or less than) 50 nm, measured with transmission electron microscope.

To prepare a stable BST dispersed solution, BST nanoparticles were dispersed in n-methyl-2-pyrrolidinone (NMP) which is a well-known basic solvent because the surface of BST

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14. ABSTRACT To overcome conventional organic thin film transistors (OTFTs) associated with high operating voltage due to the low charge carrier mobility of organic semiconductors, this work implements high dielectric constant gate insulators for enhancing field-induced carrier density. For the high dielectric constant material, the work investigates nanocomposite films that consists of cross-linked poly-4-vinyl phenol (PVP) and (Ba,Sr)TiO3 (Barium strontium titanate; BST)					
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nanoparticles was acidic. And then this solution was ultra-sonicated and centrifuged to obtain nearly non-aggregated particles in solution. The resulting BST dispersed solution was very stable and there was no precipitation even after 1 month aging of this solution at room temperature. PVP and cross-linking agent were added into this BST dispersed solution to prepare a BST dispersed polymer solution. BST particle content was varied from 0 to 70wt% to the amount of total solid (BST, PVP and cross-linking agent) and cross-linking agent content was 25wt% to the amount of PVP and cross-linking agent.

Crosslinkable PVP/BST solutions were spun onto pre-cleaned heavily doped ($\rho \sim 0.002 \Omega\text{cm}$) Si wafer. The solution coated wafer was then prebaked at 80°C for 20 min followed by curing at 220°C for 1 hr in furnace under N₂ atmosphere. Thickness of cured films was ~ 300 nm, which was determined by ellipsometer. 40 nm-thick pentacene (Aldrich, as-received) was deposited onto cured PVP/BST films coated substrate by organic molecular beam deposition. Gold electrodes were thermally evaporated on the pentacene through shadow mask. The channel length and the channel width were 100 μm and 1500 μm , respectively. Electrical characteristics of BST/PVP nanocomposite TFTs were measured in an air atmosphere using both Keithley 2400 and 236 source/measure units

Rms roughness of dielectric layer was characterized with tapping mode AFM (Digital Instrument Multimode SPM). The capacitance measurement was performed to determine dielectric constants of BST/PVP nanocomposites using Agilent 4284 precision LCR meter at 1 MHz.

Result and discussion

The variation of rms roughness and dielectric constant of PVP/BST nanocomposite dielectric layer were shown in Figure 1 and 2. Both dielectric constant and rms roughness increased with BST particle content.

Figure 3 shows the current density-electric field characteristics of PVP/BST

nanocomposite films. Leakage current through nanocomposite films increases with BST content in polymer matrix. Because a portion of interface formed between BST nanoparticles and PVP matrix increase considerably with increasing BST content in polymer matrix, electric current flow along a BST/PVP interface can cause high leakage current through nanocomposites as a BST content in polymer matrix increases.

Figure 4 shows the electrical characteristics of pentacene TFTs with BST/PVP nanocomposite films. Carrier mobility and threshold voltage of pentacene TFT without BST nanoparticles are $0.198 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$ and -13.2 V , respectively. An on/off ratio is more than 10^6 . On the other hand, pentacene TFTs with BST nanoparticles exhibit a higher field-induced current by a factor of about two at the same gate voltage as shown in Figure 4 (b). The extracted mobility of PB30 TFT from its transfer characteristics (Figure 4 (a)) increases to $0.251 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$ when compared with PB00 (pentacene TFT without BST nanoparticles) and a threshold voltage decreases from -13.2 V to -9 V as BST content increases. On/off ratio of pentacene TFTs with BST nanoparticles decrease to 10^5 , about one order smaller than that of pentacene TFTs without BST. The electrical characteristics of the devices with different BST particles content are summarized in Table 1.

In our system, both rms roughness and dielectric constant of the PVP/BST gate dielectrics increased with BST particle content. In general, the rougher gate dielectric gives rise to the larger transport activation energy and trap distribution width in pentacene TFTs, leading to a decrease of carrier mobility. On the other hand, because high dielectric constant of gate dielectrics can induce more carriers in the channel when TFTs are operated by applying gate voltage, carrier mobility of pentacene TFTs increase. These phenomena can be explained by multiple trapping and release model. Therefore, a possible deterioration of device performance by rough surface of gate dielectrics can be compensated by higher dielectric constant in this system. In case of PB50 device, although the highest density of charge carriers in this system can be achieved in the channel because of the highest dielectric constant of

PB50 nanocomposite, a very rough surface of gate dielectrics in PB50 gives rise to low field induced current in comparison with the PB30 device (Figure 4 (b)).

In summary, we have demonstrated that electrical performance of pentacene TFTs can be enhanced by increasing dielectric constant of gate dielectrics with BST dispersed PVP nanocomposites and these nanocomposites can offer an easy way to prepare dielectric-constant-tunable gate dielectrics for OTFTs.

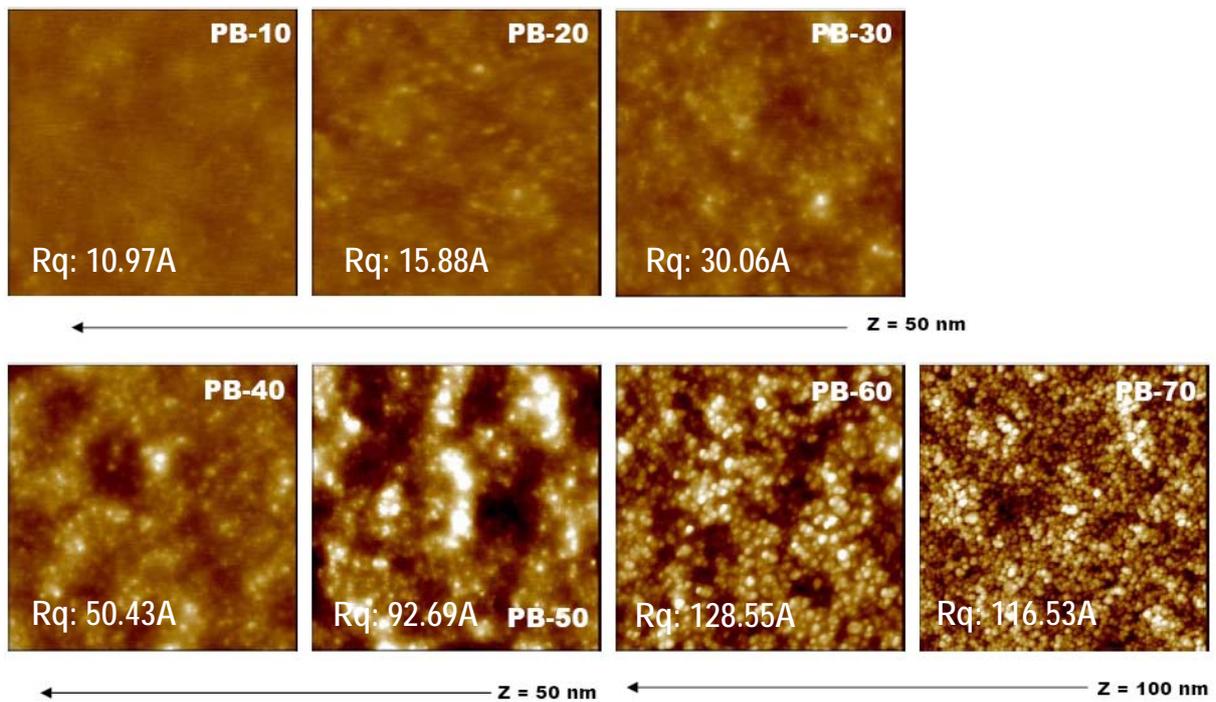


Figure 1. Surface morphology of PVP/BST nanocomposites gate dielectrics

PB-XX: PVP/BST-BST content

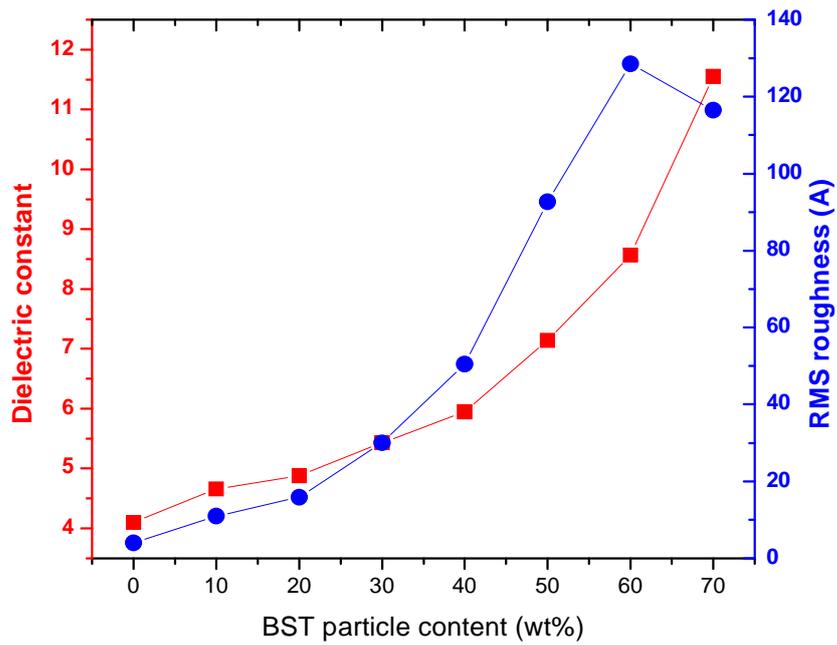


Figure 2. Dielectric constant and RMS roughness of PVP/BST nanocomposites gate dielectrics

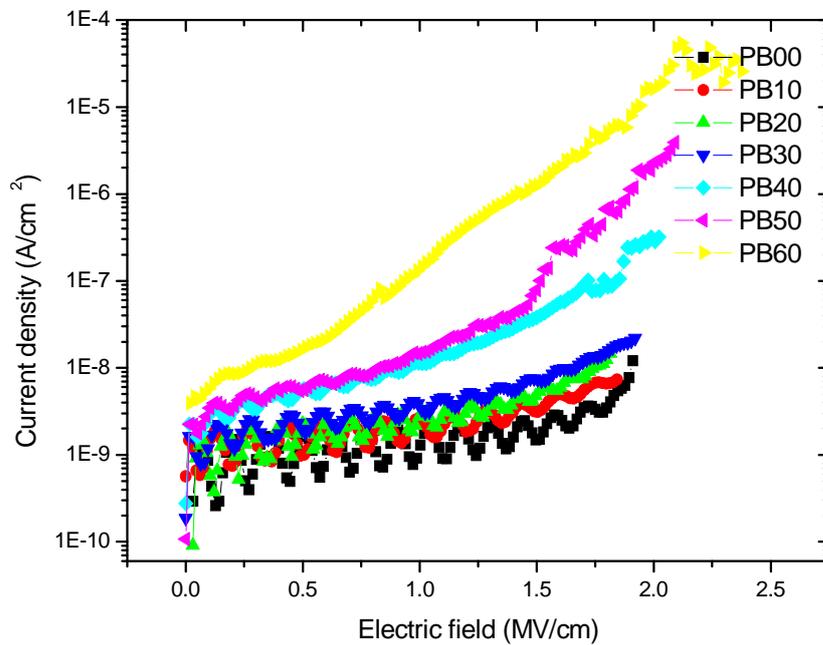


Figure 3. Leakage-current characteristics of PVP/BST nanocomposites gate dielectrics

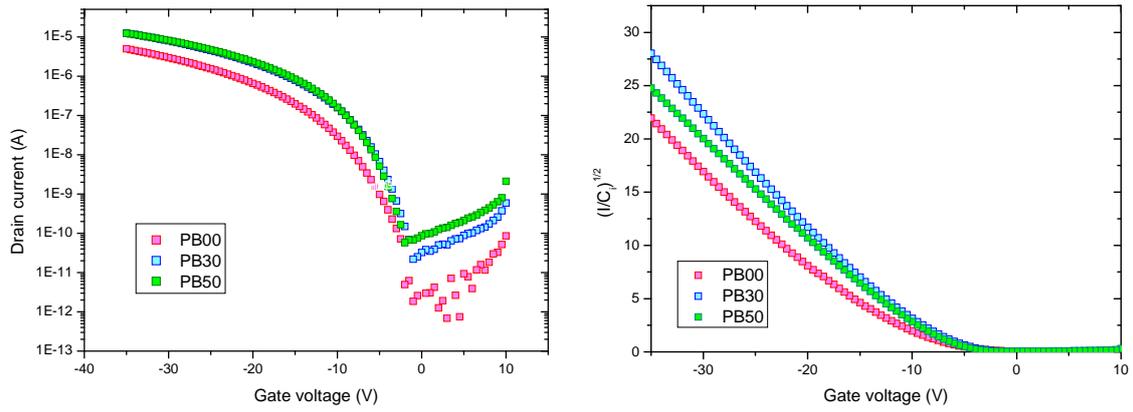


Figure 4-(a). Transfer characteristics of PVP/BST TFTs (Saturation Regime)

VG = 0 ~ -35 V (step -7 V), VDS = 0 ~ -35 V

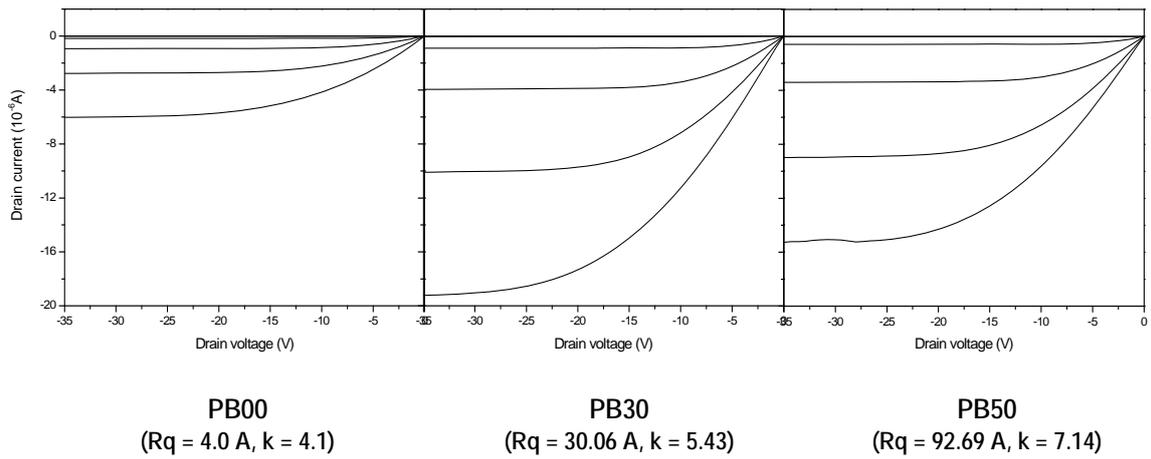


Figure 4-(b). Out characteristics of PVP/BST TFTs

	Capacitance (nF/cm ²)	Roughness (nm)	Dielectric constant	Mobility (cm ² /Vs)	V _{th} (V)	On/off ratio
PB00	9.84	0.4	4.10	0.198 ± 0.014	-13.2	10 ⁶ -10 ⁷
PB30	15.88	3.0	5.43	0.251 ± 0.012	-10.4	~5X10 ⁵
PB50	20.14	9.3	7.14	0.180 ± 0.009	-9.0	~1X10 ⁵

Table 1. Electrical parameters of PVP/BST TFTs