

Low-operating voltage Pentacene FETs with high dielectric constant polymeric gate dielectrics and its hysteresis behavior

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Introduction

Organic field-effect transistors (OFETs) have received considerable interest in recent years, and intensive studies have made it possible to achieve device performances comparable to those of amorphous silicon transistors¹⁻³. However, OFETs often suffer from high operating voltage due to the low charge carrier mobility of organic semiconductors. Hence, for the applications that require high field-induced current at low voltage, OFETs are still not the suitable candidate. Since the field-induced current density is proportional to the capacitance of gate dielectric, the way to increase field induced current density is to use high dielectric constant materials as a gate dielectric or to reduce the thickness of gate dielectric. Therefore, we use amorphous polymer with high dielectric constant ($\kappa \sim 12$) as a gate dielectric to make low-operating voltage OFETs.

Experimental

Cyanoethylated poly(vinyl alcohol) (CR-V, Shin-Etsu Chemicals) is used as a gate dielectric and has a high dielectric constant ($\kappa=12$). The chemical structure of CR-V is shown in the inset of Figure 1; in CR-V, 75% of the side groups are cyanoethyl groups and 25% are hydroxyl groups. Poly(melamine-co-formaldehyde) methylated ($M_n=511$, Aldrich) was used as the cross-linking agent and N-methyl-2-pyrrolidinone (Aldrich) was used as the solvent. The concentration of the cross-linking agent with respect to the total amount of solute was 15 wt%. Pristine CR-V and the CR-V solution containing the cross-linking agent were spun onto pre-cleaned heavily doped ($\rho \sim 0.002 \Omega\text{cm}$) Si wafers and pre-baked at 80°C for 20 min. The pre-baked CR-V with cross-linking agent was further cross-linked at 130°C for 12 h in a vacuum oven. A 50 nm thick pentacene active layer (Aldrich, without purification) was pattern-deposited through a shadow mask onto both dielectrics at a rate of 0.1–0.2 Å/s by using organic molecular beam deposition. The source/drain electrodes were defined on the pentacene films by thermally evaporating gold through a shadow mask. The channel length (L) and width (W) were 100 μm and 1500 μm , respectively. The electrical characteristics of the pentacene FETs were measured under ambient conditions using Keithley 2400 and 236 source/measure units. The surface morphologies of the gate dielectrics and the pentacene thin films were characterized with tapping mode AFM (Digital Instrument Multimode SPM).

Results and discussion

We use CR-V, amorphous polymer with high dielectric constant ($\kappa \sim 12$), as a gate dielectric. Since pristine CR-V dielectric itself exhibit low dielectric strength and poor solvent resistance, we cross-linked the polymer gate dielectric by using a curing agent. This cross-linked CR-V dielectric exhibited good insulating properties (leakage current density $\sim 10^{-8} \text{Acm}^{-2}$), smooth surface (rms roughness $\sim 3 \text{\AA}$) and improved pentacene morphology [Figure 1,2]. Using this dielectric, we prepared pentacene FETs which showed high mobility ($\sim 4 \text{cm}^2/\text{Vs}$) at low operating voltage ($\sim 4 \text{V}$) and small subthreshold slope (120 mV/decade). However, considerable hysteresis was observed in our devices during I_D - V_G characterization. Hysteresis behavior in our case may be due to slow polarization because artificially large currents appeared when devices were scanned with moderate speed. We believe that water molecules or ion impurities in the dielectric layer are responsible for slow polarization which can lead to the hysteresis measured during I_D - V_G characterization. To remove this effect, we reduced the thickness of dielectric layer and modified the curing condition. Hence, we can clarify the origin of the hysteresis and significantly reduce the hysteresis in pentacene FETs with high- κ polymer gate dielectric [Figure 3].

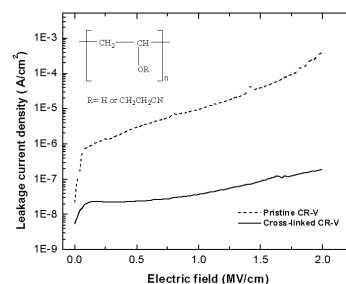


Figure 1. Leakage current density - electric field (J - E) characteristics of pristine CR-V and the cross-linked CR-V dielectric. Inset: the chemical structure of CR-V.

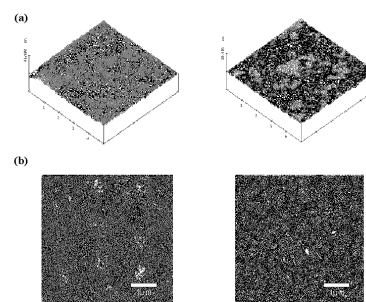


Figure 2. (a) The AFM height-mode images for pristine CR-V dielectric (left image) and the cross-linked CR-V dielectric (right image) and (b) the AFM height-mode images for pentacene on the pristine CR-V dielectric (left image) and on the cross-linked CR-V dielectric (right image).

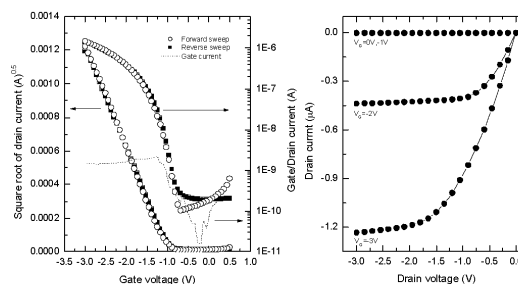


Figure 3. (a) Transfer characteristic of pentacene FET fabricated with pristine CR-V dielectric. Inset: the device structure of OFETs, (b) Transfer characteristic, and (c) Output characteristics of pentacene FET fabricated with cross-linked CR-V dielectric.

Conclusions

This work has demonstrated the potential of using high- κ polymer, CR-V, as gate dielectric for low-operating voltage OFETs. Pristine CR-V dielectric was cross-linked in the vacuum to make good insulating properties and remove small molecules such as water. The cross-linked CR-V dielectric exhibited high dielectric strength, smooth surface, and improved pentacene morphology compared to pristine CR-V dielectric. In particular, hysteresis behaviors intimately associated with device stability are notably improved. Such enhanced dielectric properties allow pentacene FETs to achieve high device performance at low-operating voltage.

References

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