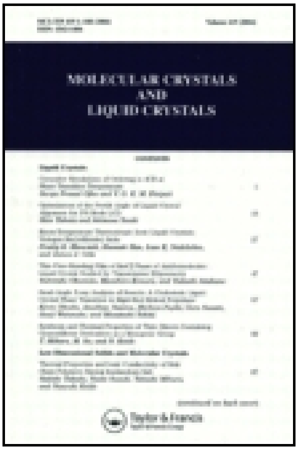

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Effect of Surfactant on Preparation of Poly(4-Vinylphenol)/Titanium Dioxide Composite for a Gate Insulator of Organic Thin Film Transistors

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Composite materials of poly(4-vinylphenol) (PVP) and titanium dioxide (TiO_2) nanoparticles were fabricated via a spin coating process in order to enhance dielectric properties for a gate insulator application of the OTFT in this study. In order to improve dispersion stability of the TiO_2 nanoparticles in the polymeric solution during the process, a surfactant was also adopted onto the solution mixture. The dispersion property was observed by measuring sedimentation time of TiO_2 particles in the polymeric solution, and the effect of surfactant on the surface morphology of the dielectric layer was further analyzed by using atomic force microscopy. Dielectric properties of the PVP-TiO_2 composite and performance of OTFTs with the PVP-TiO_2 composite insulator are presented, along with their effects on device performance with pentacene layer as a semiconductor.

Keywords: composite; dielectric; gate insulator; OTFT

INTRODUCTION

In recent years, the use of organic materials for thin film transistor (OTFT) has attracted great interest for a variety of large area electronic

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applications [1,2]. They have been regarded as one of the most important components for a flexible display and a low-end electronic, because of their many advantages such as firm adhesion to plastic substances, lower manufacturing temperatures, lower-cost deposition process, and lower power consumption [3–5]. However, those OTFTs have been mainly fabricated from organic semiconductors and inorganic gate insulators [6,7].

Concurrently, the inorganic and polymeric hybrid materials have been investigated for their application in the OTFTs, because flexibility and lightness of the polymers can make them versatile due to the remarkable electrical properties and thermal stability of inorganic materials [8]. Poly(vinyl acetate)(PVAc)/clay nanocomposite particles were reported to be used for gate insulators [9,10]. However, these composite layers were found to have slightly lower OTFT performance due to the roughness of surface morphology. Furthermore, in order to induce the surface roughness and to enhance the performance of the OTFTS, TiO_2 nanoparticles, which have small size of 50 nm with high dielectric constant, were applied as inorganic particles for the hybrids gate insulator.

In this study, the composite of PVP matrix and TiO_2 nanoparticles was synthesized for a potential application on the gate material, since in general polymer/inorganic composite materials have many advantages such as processibility, thermal stability, flexibility and producability. Furthermore, in order to investigate the effect of the TiO_2 particle-dispersion on the electrical properties, non-ionic surfactant of polysorbate 80 (Tween80) was used to modify the surface affinity of TiO_2 particles for their uniform distributions in the solution. The dispersion stability was characterized in terms of turbidity of the solution. The effect of dispersion properties on the surface roughness of the dielectric layer was observed with atomic force microscopy (AFM). The performance of OTFT with PVP-TiO_2 composite, as a gate insulator, was also presented, in addition to the effect of surfactant for preparing the composite material. Their effects on the device performance with pentacene layer as a semiconductor was further characterized.

EXPERIMENTAL

In order to synthesize organic-inorganic composite materials, both PVP (Sigma Aldrich, USA) and TiO_2 (Ishihara Sangyo Kaisha, Japan) were used. At first, 1 wt% of PVP was dissolved in ethanol, and then 0.01 wt% of TiO_2 nanoparticles were dispersed in the solution. Nonionic surfactant Tween80 was used as a dispersant for TiO_2 particles in the polymeric solution. A mixture solution of PVP and titania nanoparticles was ultrasonicated for 5 h, and then dispersed by using a homomixer for 24 h for uniform dispersion.

For the fabrication of OTFTs, an Al gate electrode was thermally set on a glass substrate using the first shadow mask. 2000 Å-thick film of the mixture as a gate insulator was spread by a spin-coating process, and then baked at 60°C for 10 min and consecutively at 100°C for 20 min in a vacuum dry oven. Pentacene layer as an organic semiconductor was thermally evaporated through the second mask onto the insulator with the thickness of about 600 Å. Subsequently, a 500 Å-thick Au layer was thermally evaporated through the third mask for the source and drain contacts.

Electrical characteristics were investigated using a high current source measuring unit (Keithley) and semiconductor analyzer unit (EL421C, Elecs Co.). The surface morphology of the fabricated gate insulator layer was observed with an AFM (XE150, PSIA Inc.).

RESULTS AND DISCUSSION

In order to examine dispersion stability of the TiO_2 in the PVP solution, turbidity of the solution was measured. Figure 1 shows light

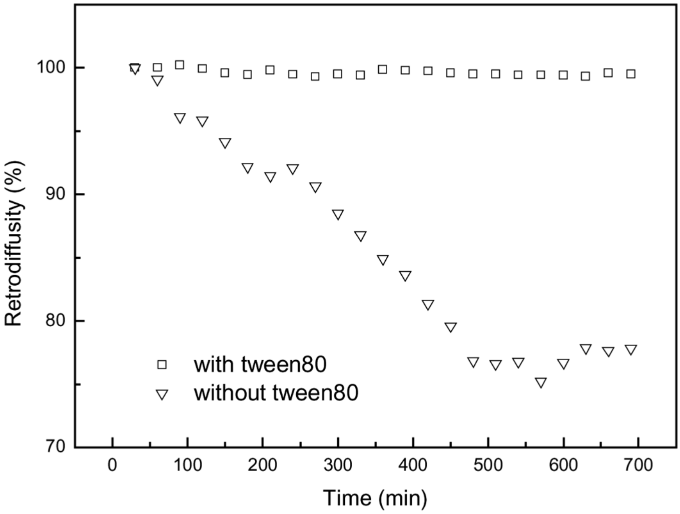


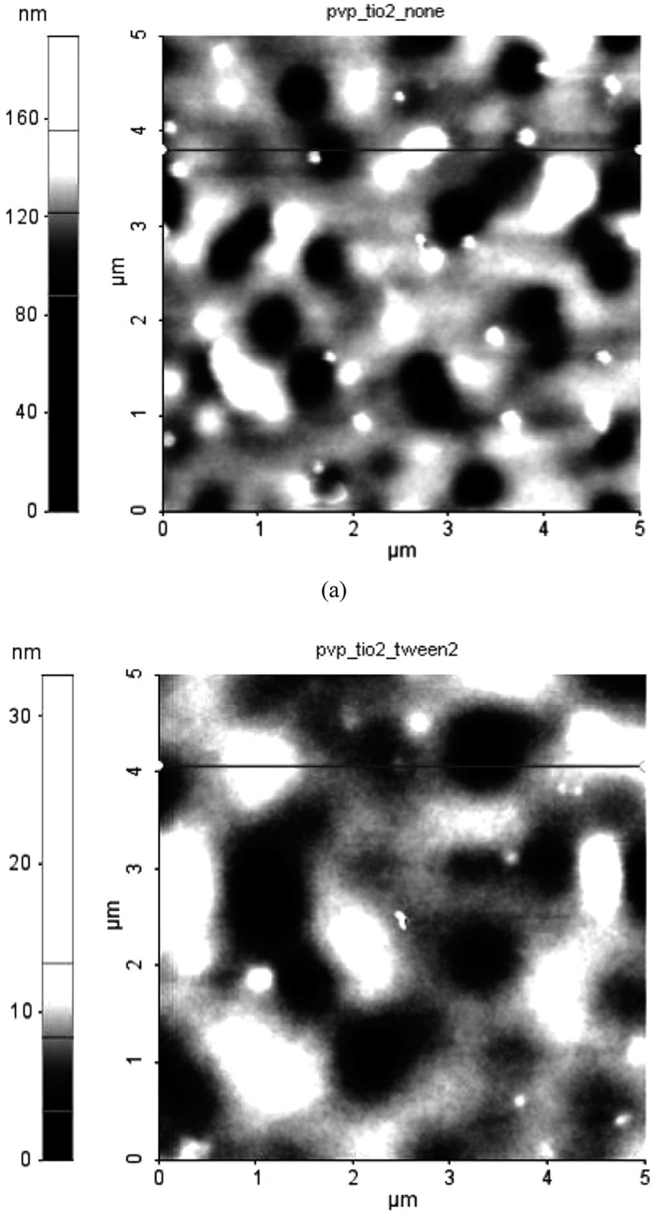
FIGURE 1 Turbiscan image of PVP/TiO_2 solution.

retrodiffusion through a certain position of the solution, in which the value of retrodiffusion for the PVP/TiO_2 decreases with time in the absence of surfactant, representing the coalescence of TiO_2 nanoparitcles in the PVP solution [11]. On the other hand, the value for the composite materials modified by surfactant maintained its level with small variance for about 12 h. This result indicates that TiO_2 particles are uniformly dispersed in the PVP solution and the surfactant works to split the aggregates into nanoparticles. Figure 2 shows the AFM image of surfactant effects on the surface morphology of the dielectric layers. It was observed that the many bright domains of small area were formed when the TiO_2 was dispersed in PVP matrix without a surfactant. Individual size of the domains increased when the solution contained a surfactant. In addition, the scale bars of the images indicated that the height of the domains drastically decreased by the addition of surfactant. It can affect the grain size of conductive layers, indicating that the surfactant affects the dispersion TiO_2 in the polymer matrix. However, the domain in Figure 2(b) shows that the TiO_2 particles are still aggregated, even though their dispersion state is remarkably improved.

Figure 3(a) shows the output characteristics of the composites material-based OTFTs without a surfactant. It is clearly seen that the device performance was deteriorated in the low drain voltage region due to the critical gate leakage current. This is resulted from that TiO_2 nanoparticles are aggregated with each other. In Figure 3(b), the output characteristic of the composite materials based OTFTs with the surfactant was compared to that of the pure polymer based OTFTs. When the surfactant was adopted, the gate leakage current notably decreased, even though the composite materials still have higher gate leakage current compared to the pure polymer based device. For the transfer characteristic measurements, the V_G was swept from 5 to -40 V with the sweep step of -0.5 V at the V_D of -20 V, and from the curve of the square root of I_D versus V_G, field effect mobility (μ_{eff}) in the saturation region was estimated using Eq. (1):

$$I_{D,sat} = \frac{W\mu_{eff}C_i}{2L}(V_G - V_T)^2 \tag{1}$$

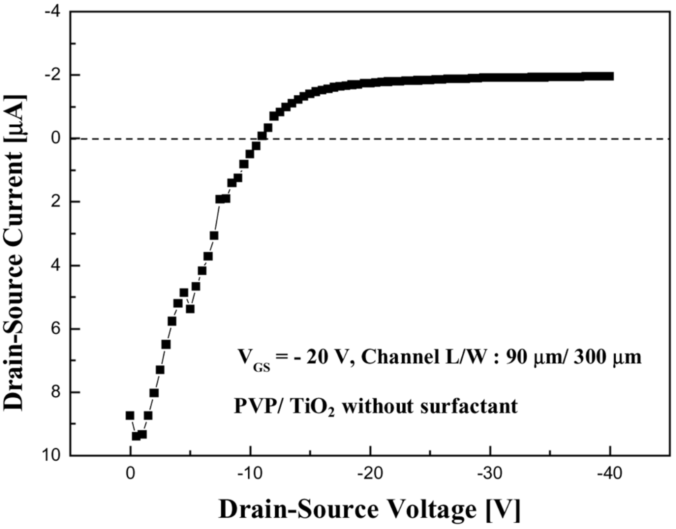
where C_i is the capacitance of the gate insulator per unit area, V_T is the threshold voltage. According to the results from the general OTFT performance, the composite based insulator which is modified by surfactant contributes to lowering the threshold voltage and enhancing the sub-threshold slope of OTFTs due to its high dielectric constant.



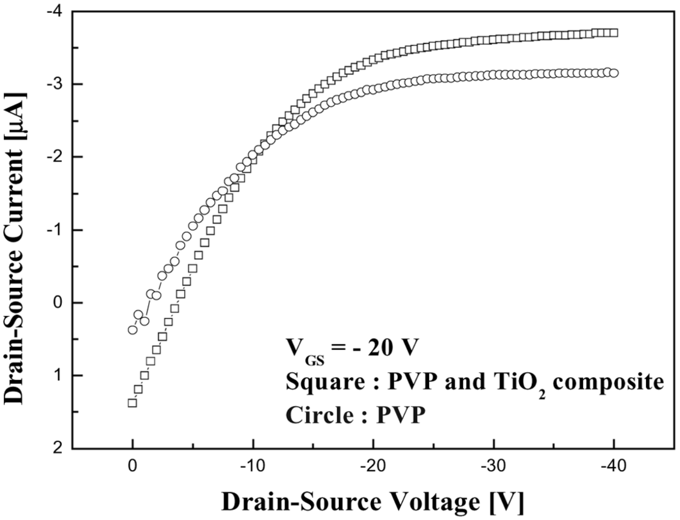
(a)

(b)

FIGURE 2 AFM images of PVP/TiO_2 composite materials (a) without surfactant and (b) with surfactant.



(a)



(b)

FIGURE 3 Plots of drain-source current vs. voltage for the nanocomposites of PVP and TiO_2 (a) without surfactant and (b) with surfactant.

CONCLUSION

PVP and titanium dioxide nanocomposites were fabricated as gate insulator materials. In device performance, the threshold voltages and sub-threshold slopes of composites materials were lower than those from the pure polymer, because of a high dielectric constant of the inorganic particles. The nanocomposite materials, however, have the lack of gate leakage currents and mobility due to the aggregation of TiO_2 nanoparticles in the polymer matrix. The aggregation issue was possible to be solved by using surfactant in some degree. The composite is expected to have enhanced dispersion stability by selecting a more effective surfactant working on the surface of TiO_2 nanoparticles. It is also expected that the composite based OTFT can be developed by making continuous distribution inorganic particles in the polymer matrix.

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