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Interface Trap Reduction Based on Poly(styrene-co-methyl methacrylate)/Hafnium Oxide Bilayer Dielectrics for Low Voltage OTFT

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1. Introduction

In recent years, organic thin film transistors (OTFT) have become promising candidates for portable and flexible electrons due to their distinct advantages such as large area, light-weight, low-cost and low temperature fabrication. For portable applications, the development of gate dielectric is the main issue to develop low power consumption OTFTs. So far, general insulators for low voltage OTFT including self-assembled monolayer (SAM) [1], high k material [3], multi-component insulator [4, 5], hybrid organic/inorganic materials [6, 7] are applied to increase the dielectric constant and reduce the dielectric thickness of polymer, leading to gate capacitance enhancement.

Here we demonstrate a random copolymer poly (styrene-co-methyl methacrylate) (PS-r-PMMA) / hafnium oxide (HfO_2) bilayer dielectrics as the gate insulator to realize a low voltage OTFT. Moreover, the effects of copolymer surface modification on interface traps are reported. The pentacene based OTFT utilizing the bilayer dielectrics can operate under -5V with a subthreshold swing of 0.33V/dec.

2. OTFT fabrication

The bottom gate OTFT used in this study was shown in Fig. 1. The heavily doped silicon was utilized as the gate electrode. After wafer clean, a 80-nm-thick HfO_2 dielectric was deposited on heavily doped silicon substrate by rf sputtering at room temperature. The PS-r-PMMA random copolymer purchased from Ardrich (M_w=100,000~150,000) was dissolved in toluene as concentration of 20 mg/ml. Sequentially, PS-r-PMMA was spin coated on HfO_2 and heated in an oxygen and moisture free environment at 170 ^oC for 24 hours. Such a high temperature (above glass transition point T_g) was required to allow the PS-r-PMMA chains obtain sufficient energy to diffuse and end graft on oxide material [8]. After heating process, the sample was rinsed with toluene to remove unattached chains of PS-r-PMMA, obtaining a desired thickness of PS-r-PMMA film about 10nm. For organic channel layer, pentacene was deposited by thermal evaporation at a base pressure of 2×10^{-6} torr without substrate heating. The deposition rate was maintained at 0.1-0.2nm/s and the thickness was 40nm. Finally, the gold material was used to make the source/drain electrodes, forming the ohmic contact between active layer and source/drain regions.

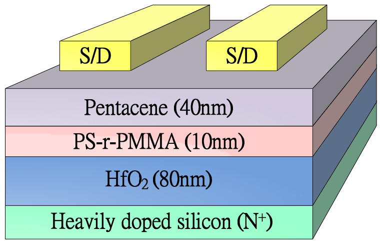

Fig. 1 Schematic view of OTFT with PS-r-PMMA/HfO_2 bilayer gate dielectric.

3. Device characteristics

The current–voltage (I–V) characteristics of the OTFT were measured by an HP 4145A semiconductor analyzer. Furthermore, in order to confirm the effect of PS-r-PMMA on surface modification, the capacitance–voltage measurement of metal/insulator/semiconductor (MIS) was carried out by Agilent E4980A impedance analyzer. All of the electrical properties of devices were characterized in ambient air. Fig. 2 showed the transfer curves of pentacene based OTFT with bilayer dielectrics. The threshold voltage, subthreshold swing and on/off current ratio were -2.9V, 0.33 V/dec and 10^4-10^5, respectively. The mobility extracted from the saturation regime was 0.26 $cm^2/V{\cdot}s$. It was worthy to notice that on/off current ratio was much improved by PS-r-PMMA layer due to the leakage current reduction. For single HfO_2 dielectric, I_{on}/I_{off} ratio was 10^3. By stacking PS-r-PMMA on HfO_2, the leakage current was decreased to 10^{-11} A which is reduced by magnitude of two orders

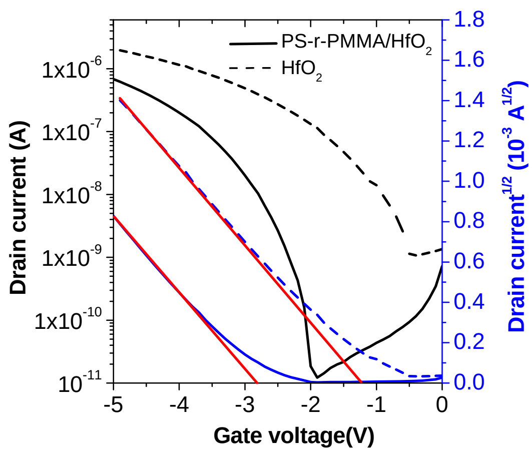

Fig. 2 Transfer curves of pentacene based OTFT with PS-r-PMMA/HfO_2 gate dielectrics.

comparing with HfO_2 single layer. The performance of pentacene based OTFT with PS-r-PMMA/HfO_2 dielectrics and single HfO_2 was listed as Table I. Moreover, the semiconductor/dielectric interface was also improved significantly according to subthreshold swing reduction. This phenomenon was regarded as the screening effect of PS-r-PMMA on polarity HfO_2. The polar dielectric interface may broaden the distribution of density of state (DOS). Nonpolar PS-r-PMMA covered the dipoles of HfO_2 surface, usually leading to semiconductor/insulator interface improvement and concentrated the DOS distribution [2].

Table I Performance of OTFTs with various dielectrics

Dielectric	Vt (V)	μ_{sat} (cm^2/V·s)	S.S. (V/dec)	I_{on}/I_{off}
PS-r-PMMA/HfO_2	-2.9	0.26	0.33	10^4-10^5
HfO_2	-1.25	0.2	0.59	10^3

The results of C-V measurements with MIS structure at 1MHz were shown in Fig. 3. For the single HfO_2 dielectric, depending on applied voltages from -10V to 10V, the device went from the accumulation into depletion slowly as a result of interface trap effect. By contrast, the device with Ps-r-PMMA/HfO_2 bilayer dielectrics performed a rapid capacitance decreasing form -3V to 3V that indicated interface property was significantly improved, corresponding to S.S calculated. Moreover, the higher depletion capacitance of single HfO_2 dielectric was observed. This was attributed to carrier trapped by the interface or bulk defects and result in the reduction of depletion width, causing a high capacitance.

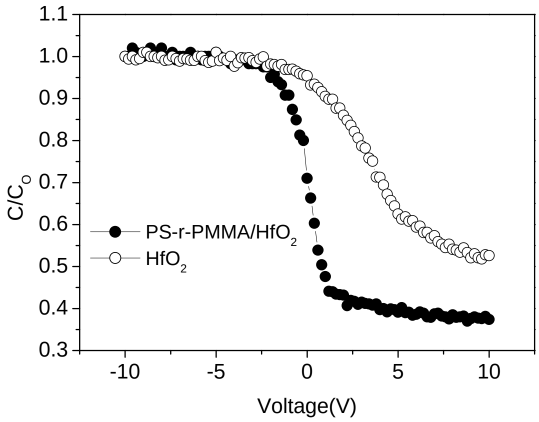

Fig. 3 Capacitance of MIS diode versus applied voltage.

The AFM images of pentacene evaporated on PS-r-PMMA/HfO_2 bilayer dielectrics and single HfO_2 were shown in Fig. 4. The morphology of pentacene deposition depended on surface energy of the dielectric. The contact angle of PS-r-PMMA was roughly about 85^o that indicated hydrophobic property. Such a hydrophobic character provided the sufficient surface energy and resulted in pentacene with island structure. The medium grain size of pentacene can be observed in Fig. 4(a). On the other hand, the pentacene growth on HfO_2 performed the large grain size with dendritic structure. However, the large voids between the pentacene grains behaved as the scattering centers that affected the carrier transport in semiconductor. Thus, the mobility was not as high as the medium grains with good interconnection.

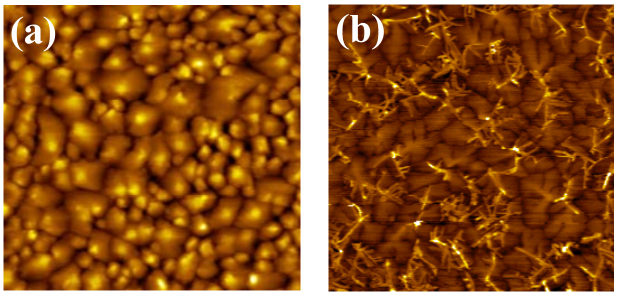

Fig. 4 AFM images of 40-nm thick pentacene evaporated on (a) PS-r-PMMA/HfO_2 bilayer dielectrics (3×3μm^2) (b) HfO_2 single dielectric (10×10μm^2).

4. Conclusions

In summary, we have demonstrated a low voltage OTFT based on PS-r-PMMA/HfO_2 bilayer dielectrics. By stacking PS-r-PMMA on HfO_2 dielectric, the semiconductor/insulator interface was significantly improved. The leakage current and subthreshold swing were decreased obviously. The OTFT with such a low k/high k stack dielectrics can operate below 5V, with a sufficient on/off current ratio of 10^5, a subthreshold swing of 0.33V/dec, and mobility of 0.26 cm^2/V·s.

Acknowledgements

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