A NOVEL HIGH-K (K > 40) GATE DIELECTRIC FOR PENTACENE ORGANIC THIN FILM TRANSISTORS

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Introduction

Organic semiconductors have emerged as one of the important low cost materials in semiconductor world with wide range of applications such as organic light-emitting diodes (OLEDs), organic photovoltaic cells (OPVs), backplanes for flat panel displays and radio frequency identification (RFID) tags [1-3].
Many of the well-developed organic semiconductors including pentacene are p-type materials because they tend to transport holes better than electrons and have a better atmospheric stability. Therefore, most of the work reported in the literature is based on p-type organic thin film transistors (OTFTs), which operate at high operating voltages [4, 5]. Low operating voltage OTFTs with inorganic high-k as gate dielectric have also been demonstrated recently [6, 7].
In recent years there has been a growing interest in developing new magnetic and ferroelectric materials at room temperature. This is mainly due to their potential for remarkable device applications and fascinating physics. These materials typically have very high dielectric constant (K > 40) and can be used as gate dielectrics for transistors and for memory applications [8-11]. More over, there is coupling between magnetic and ferroelectric phenomenon (ME coupling), which gives an extra degree of freedom for the device design.
In this work, we have shown the possibility of using $Bi_{0.7}Dy_{0.3}FeO_3$ (BDFO), a recently-developed room-temperature novel high-K multiferroic thin film as a gate dielectric material in pentacene based organic transistors [12-14]. The processing characteristics and demonstrated performance of OTFTs suggest that BDFO can be competitive for existing or novel thin-film-transistor applications requiring large-area coverage, structural flexibility, low-temperature processing and especially low cost process.

Experiment

Various structures with several different combinations of semiconductor materials have been tried to achieve the desired performance from OTFTs [1]. Top contact structures have been made in this work, as it gives good ohmic contact with semiconductor material being placed on the top, preserving uniformity. Therefore, a better 'ON' current can be achieved using this structure. In our experiment the RCA cleaned n++-type wafer which acts as gate, is used to make the top contact OTFT structure as shown in Fig. 1, the BDFO gate dielectric of 150 nm is deposited by Pulsed Laser Deposition (PLD) technique. Here the semiconducting material pentacene of 50 nm thickness is deposited by thermal evaporation on top of the BDFO gate dielectric. Finally contacts are patterned on the top of it using shadow mask.

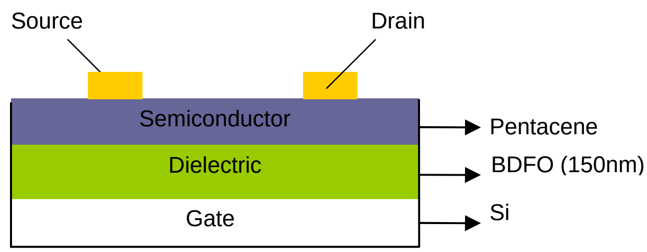


Fig. 1 Bottom-gate top-contact OTFT using BDFO as gate dielectric.

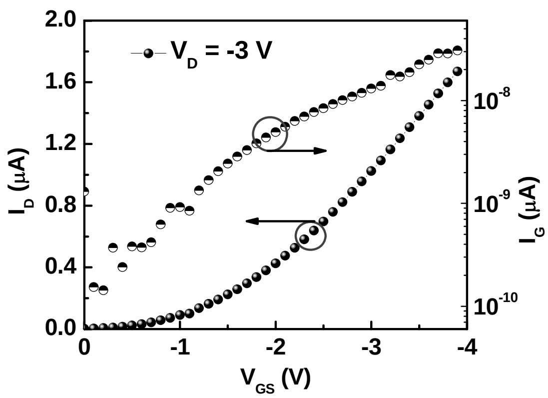
Fabrication Process

After RCA cleaning, the wafers were loaded in PLD chamber. The typical conditions used for deposition to get high quality films are as follows. Laser Energy: 2.9 J/cm^2, Target to substrate distance: 4.5 cm, Substrate temperature: 690°C, Oxygen pressure: 0.4 torr. The deposition was carried out for 15 minutes at a repetition rate of 10Hz in order to obtain a film thickness of 150 nm. The samples were then annealed in the chamber under oxygen ambient.
On top of the BDFO-deposited sample pentacene was deposited in a standard thermal evaporation system. The substrate temperature was maintained at 60°C for good film growth and the deposition was done when the pressure was nearly ~ 3.6×10^{-5} mbar. The thickness of the pentacene film was 50 nm with the deposition rate nearly 1Å/min. Finally the source and drain contacts of

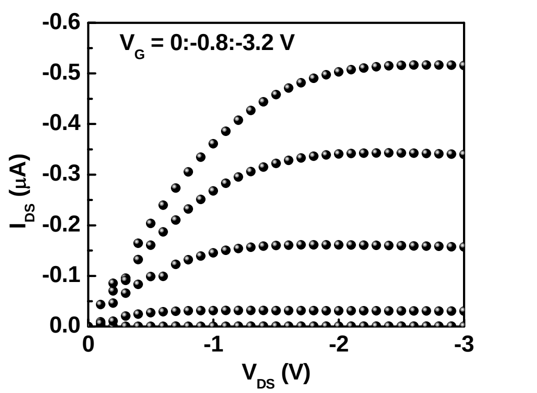
gold (~ 80nm thickness) were made with the help of a shadow mask using sputtering at a pressure of 2.6×10^{-3} mbar to complete the transistor structure.

Results and Discussion

The Capacitance versus Voltage (CV) data of the high-K multiferroic material BDFO was characterized. It shows dielectric constant of 43 at 1 KHz frequency and gate capacitance of $\approx 2.54\times10^{-7}$ F/cm^2. It also exhibits a very low leakage density of $\approx 1.025\times10^{-7}$ A/cm^2 at 3 V which is one of the important requirements for an organic transistor. The pentacene-based organic transistors with BDFO as a gate dielectric were fabricated and characterized. These devices showed a good transistor performance for which a typical transfer (I_D-V_{GS}) and output (I_D-V_{DS}) characteristics obtained is as shown in Fig. 2 for W/L = 1030/40 (sizes in μm). The performance parameters are $V_t \approx -1$ V, mobility $\mu \approx 3.69\times^{-2}$ cm^2/V.s and the I_{on}/I_{off} ratio ≈ 5.0 x 10^2.



(a)



(b)

Fig. 2 Transistor characteristics (a) Drain current (I_D) versus gate voltage (V_{GS}) (b) Drain current (I_D) versus drain-source voltage (V_{DS}) of the OTFT with BDFO as the gate dielectric.

Conclusion

In this work we have demonstrated a pentacene OTFT using a novel multiferroic material (BDFO) with a high dielectric constant value (k = 43) as a gate dielectric. The results suggest that BDFO is a good candidate as a gate dielectric as it shows a low leakage current density, good ON/OFF ratios. The performance of these fabricated organic transistors such as mobility and current on/off ratio can be further improved with the help of proper surface treatments.

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