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Enhanced Model of Thin Film Organic Field Effect Transistor for Radiation Sensing

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Abstract: ***The driving mechanism for carrier-generated Organic Feld-Effect Transistors with pentacene and vanadium pentoxide layers is discussed in this paper. Large on-currents were observed in OFETs with 35-nm V_2O_5 layer. The proposed OFET also exhibits a low threshold voltage, which is a requirement for driving FETs. Sandwich-structured devices composed of pentacene and V_2O_5 layers with high carrier injection barriers are also investigated. Verifying the dependence of the I-V properties of the device on the V_2O_5 layer thickness and investigating the UV-visible absorption characteristics of a mixed layer of pentacene and V_2O_5 molecules, we propose a model drive principle for OFETs. The characterisation of the proposed OFET confirms the capability of the device to be used as a radiation sensor which could detect gamma radiations.***

Keywords: X- Ray Diffraction, Energy Dispersive X-ray Spectroscopy, Fourier Transform Infrared Spectroscopy, Photoelectron Spectroscopy

1. Introduction

Thin Film Technology (TFT) is a growing field of scientific interest. The far developed field has already converted large transistors into minute chips. The need for large capacity in small size makes TFT always an area of interest. The incorporation of organic semiconductors into the channel of Field Effect Transistor (FET) forms an Organic FET. Field Effect Transistors are the basis for all electronic circuits and processors. The ability to create FETs from organic materials raises exciting possibilities for low cost disposable electronics. The advantages, such as flexibility, low cost, light weight, and simple fabrication processes makes the OFET more attractive. It is found that the properties of OFETs can be enhanced significantly through improvements in their structure, materials, and fabrication techniques. But high threshold voltage is a problem that is yet to be addressed in case of OFETs. To overcome this drawback, we propose a new type of OFET that has both organic and Lewis acid molecular layers. Low threshold voltage (V_t), which is a requirement for driving FETs is exhibited by this model. Here, OFETs with pentacene [1] and vanadium pentoxide active layers are fabricated, and their properties are studied. Pentacene- a material of high crystallinity, has excellent hole-transporting capabilities and can be used in the fabrication of OFETs. The sandwich-structured device composed of pentacene and V_2O_5 layers with high carrier injection barriers are also investigated. It has been reported that V_2O_5, which is a Lewis acid, can remarkably improve the current efficiency of Organic Light Emitting Diodes (OLEDs) [2]. Further characterisation of the model leads to the inference that the device can be used as a gamma ray sensor.

2. Experimental Procedure

We are aiming to construct an enhanced version of the existing model of Organic Field Effect Transistor. In order to achieve this we use different layers of materials with unique characteristics to fabricate the FET. From the electronic and optical perspective [3] V_2O_5 is an important material among other transition metal oxides in thin film form. Verification whether a Lewis acid molecular-layer-induced reduction of the threshold voltage (V_t) in an OFET with a conjugated polymer layer, would be observed in an OFET with the addition of pentacene layer is also done. We infer that sandwich-structures containing pentacene and V_2O_5 layers have high carrier injection barriers. Pentacene has the advantage of high field effect mobility [4], good photoresponsivity, ease of commercial availability, high photocurrent on off ratio etc..Vanadium pentoxide is highly stable and thin film can be easily be formed. For the purpose of low cost production we use glass/Si as the substrate. In thin film technology we can use paper,or even cloth [5].

We use Aluminium as the source, drain and gate material as it is cheapily available [6]. Silver or gold can also be used in this place. The thickness of the combined structure of pentacene and vanadium pentoxide was fixed at 70 nm. The pentacene and the V_2O_5 layers were deposited through vacuum deposition method [7] using the Hind-Hivac coating unit. The procedure is elaborated in the next section.

2.1 Coating Procedure

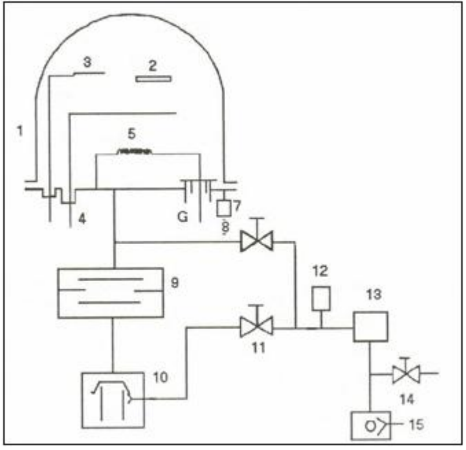

Figure 1: Schematic diagram of the coating unit

1.bell jar, 2.substrate, 3.thickness monitor, 4.source shutter, 5.electron beam gun, 6.current feed through, 7.penning guage, 8.roughing valve, 9.baffle valve, 10.diffusion pump, 11.high vacuum valve, 12.pirani gauge, 13.fore-line trap, 14.isolation valve, 15.rotary pump.

After ensuring all the switches are off and valves are closed, check the rotary oil level. Switch the plug on and allow the cooling water supply to flow. Switch the machine switch and rotary pump on. Switch on the pirani gauge and wait till the pressure 0.05m bar at GH_1. Change the combination valve to backing position. Again check the pressure at pirani gauge 0.05m.bar at GH_1. Then DP switch is made ON. Pirani gauge is turned off and wait for half an hour. Hoist up the chamber after admitting air. Load the filaments or boats with the required material on the work holder. Cover the boat with source shutter. Hoist down the chamber on the base plate. Then close the air admittance valve. Combination valve is put into roughing position. Turn on pirani gauge and check pressure at GH_2 till it reaches 0.05m bar. Turn off the pirani gauge and put the combination valve to backing position. Then slowly open the high vacuum valve. Roughing and high vacuum valve should not be turn on together. Switch on the penning gauge and check the pressure in gauge head 1. Wait until pressure at gauge head 2 reaches 2×10^8 bar. Turn on CBI and LT. The density and acoustic impedance of the coating material should be found and set in the thickness monitor. Set tooling factor. Then open the shutter and increase the current slowly till the coating starts. After the completion of coating, make the current to 0A. Then switch off the thickness monitor, LT and CBI. Close high vacuum valve, switch off DP and wait for half an hour. Close backing valve and turn off rotary switch. Finally turn off machine switch and main power supply. In the same manner we fabricated other layers on the glass substrate. In order to investigate the characteristics of this proposed model we done some characterization techniques. X-Ray Diffraction (XRD) analysis is used to determine the crystallinity of the structure. Energy Dispersive X-ray Spectroscopy (EDAX) is used for the chemical characteristics of the structure. It is based on the X ray excitation and the sample. Fourier Transform Infrared Spectroscopy (FTIR spectroscopy) analyses the polymeric organic and inorganic materials. It uses infrared light to test the structure. It is also used to find the chemical properties. Ultraviolet –visible spectroscopy utilizes light in the visible or adjacent ranges and it is greatly affected the perceived color of the chemicals involved.

3. Results and Discussion

3.1 Structural Behaviour

On a heavily doped n-type Si substrate, 100 nm thick SiO_2 layer was formed through oxidation (glass substrate can also be used). Figure 2 shows an OFET with aluminium gate electrode, n-type Si substrate, SiO_2, pentacene, V_2O_5 and aluminium source and drain electrodes [8]. Initially the channel width and length was set to be 0.15 cm and 1.5×10^{-3} cm respectively (say, device 1).

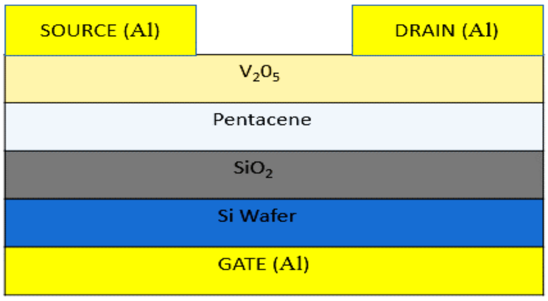

Figure 2: Structure of proposed OFET

Table 1: Thickness of different layers

Layer	Thickness (in nm)
Gate	50
Si substrate	75
SiO_2	100
Pentacene	70-x
V_2O_5	x
Source and drain electrodes	50

The optimal thickness for enhanced device performance was investigated by varying the combined thickness of the active layers. Carrier generation at pentacene-V_2O_5 interface was also analyzed by studying sandwiched-type devices (say, device 2). The area of this device was fixed at 2×10^{-3} cm^2. The characteristics of device 1 and 2 were studied at room temperature. Figure 3 shows a plot of drain current (I_D) vs. drain-source voltage (V_{DS}) at various gate voltages for x=0 and x=35 nm.

I_D follows V_{DS} linearly upto saturation and then levels off. The threshold voltage may be estimated from the $|I_D|^2$ vs. V_G plot. Due to the incorporation of V_2O_5 layer the threshold voltage was decreased [9]. We inferred that the voltage required to form a carrier accumulation layer at the interface between SiO_2 and active layers was decreased by the insertion of V_2O_5 layer. However, the mobility was found to be slightly decreased which might be due to the damage to the pentacene layer resulting from heat generated during evaporation of V_2O_5. In OFETs with thick V_2O_5 layer, ohmic currents may dominate [10]. Through photoelectron spectroscopy in air (PESA) and UV-visible absorption spectroscopy, the work functions of Al, pentacene and V_2O_5 layers were estimated to be -3.7, -4.8, and -5.6 eV, respectively, and the electron affinities of the pentacene and V_2O_5 layers were around -3.1 and -2.9 eV. In devices with both V_2O_5 and pentacene layers, a large current density was observed even though they have high injection barriers [11]. It is apparent that the interaction between pentacene and V_2O_5 molecules contributes to current conduction. Figure 4 shows the UV-visible absorption of a pentacene layer, a V_2O_5 layer, and a mixed layer composed of pentacene and V_2O_5 molecules in a 1:1 mol% ratio.

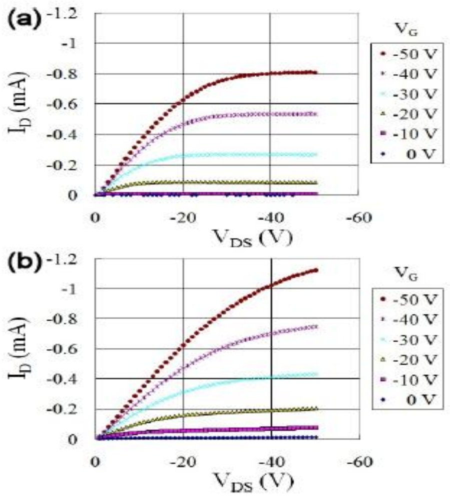

Figure 3: Output characteristics for x=0 and x=35 nm

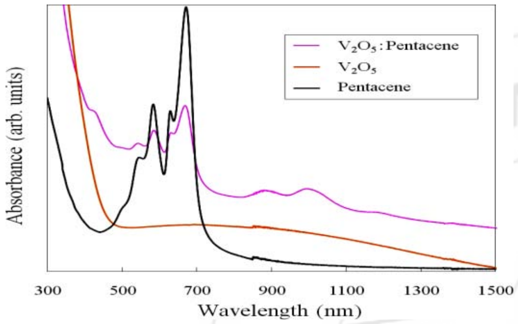

Figure 4: Absorption spectra of the device

Changes in absorption spectrum were observed at a wavelength around 1000 nm. Radical cation absorption of pentacene leads to the appearance of new absorption bands. A new ionization potential of approximately -3.7 eV was also attributed to the same reason. However, the radical anions of pentacene do not form an absorption band [12]. This might be due to the formation of charge transfer (CT) complexes in device 2. The Al electrode at the left side may be regarded as a cathode. Radical cations of pentacene may be carried towards the cathode as holes due to the ionization potential [13] of pentacene layer resulting from the applied voltage. Similarly, radical cations of V_2O_5 layer may be transported to the anode as electrons. These electrons and holes may be generated by the dissociation of CT complexes at the interface. The hole injection barrier between Al and V_2O_5 layers is higher than the energy gap between ionization potential of pentacene and new band due to CT formation. Thus a large current density was observed in device 2. Thus, we may infer that conductive holes are generated by the dissociation of CT complexes [14] at pentacene- V_2O_5 interface due to applied gate voltage. Thes holes accumulate at the SiO_2-pentacene interface. Drain current and threshold voltage (V_t) of the OFET may be significantly improved using this drive principle.

3.2 Sensing Behaviour

Organic substrates like pentacene may be used to analyze changes in properties of materials due to exposure to ionizing radiations like Ɣ (gamma) rays. We studied the effect of new energy states (formed due to exposure to radiation) in the band gap of the organic semiconductor material. An increment in the p-type doping and energy state generation in the bandgap was confirmed using photoelectron spectroscopy techniques. An increase in the conductivity of the thin film was also observed. Changes in the electrical behaviour of the OFET on exposure to radiation can be exploited to measure the intensity of Ɣ rays. Incorporation of new receptor layers or composite materials as the active layer of the OFET enables us to realize highly efficient and sensitive radiation sensors.

4. Conclusion

OFETs for different channel lengths were fabricated and their electrical properties were studied in this paper. Typical drain characteristics of OFET for various values of gate voltage were observed. An improvement in drain current and threshold voltage was observed, when pentacene and V_2O_5 layers are used in the structure of normal FET. The proposed device is particularly suitable for gamma radiation sensing applications. The behavior of the OFET can be varied by slight modifications in the dimensions and by incorporating suitable materials so as to suit the application.

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