Journal of Basic and Applied Engineering Research
p-ISSN: 2350-0077; e-ISSN: 2350-0255; Volume 2, Issue 20; October-December, 2015, pp. 1721-1723

http://www.krishisanskriti.org/Publication.html

Thin Film Organic Field Effect Transistor using Pentacene

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Abstract—*In our present study we are reporting on fabrication and characterization of pentacene based Organic semiconductor based Thin Film Field Effect Transistors (TFFETs) with rare earth oxide Eu_2O_3 as gate insulator. The transistors have been fabricated by the process of vacuum evaporation technique on perfectly cleaned glass substrates. The pentacene film morphology has been studied by XRD and found to be polycrystalline in nature. The different transistor parameters, such as, output resistance (r_d), transconductance (g_m), amplification factor (μ_A), the field effect mobility (μ_D), the Gain bandwidth product (G.Bw.), trap density and grain size of the fabricated devices have been calculated and are presented.*

1. INTRODUCTION

Organic semiconductor based Thin Film Field Effect Transistors (TFFETs) are the field effect transistors, in thin film form, which use organic semiconductor as their active material. The structure was first reported by Weimer in 1962 [1]. Basically it is an insulated-gate field-effect transistor whose operation depends on the same basic principle as that of a metal oxide semiconductor field-effect transistor (MOSFET). Organic thin film transistors are highly studied during last few years because of its variety of electronic applications, such as information display, chemical sensor, electronic paper and microelectronics [2].

The use of organic material as the active material in TFFETs was first reported by Ebisawa *et. al*. in 1983 [3]. Organic semiconductors have got the advantage that they can be grown in the thin film form, also they are compatible with plastic substrates, have lower manufacturing temperature and lower fabrication cost. For these reasons nowadays organic TFFETs are replacing the usual silicon TFFETs where large area application and flexibility are required. However these devices have low mobility (typically in the 10^{-3}-10^{-5} $cm^2V^{-1}s^{-1}$ range) consequently, they are not suitable for use in applications requiring very high switching speeds. But recent progress in organic TFFET technology made the organic electronic devices comparable to those for amorphous silicon. The mobility and the current on/off ratios are now comparable to amorphous silicon based transistors [4].

2. EXPERIMENTAL

In the present work organic TFFETs having channel length (*L*) 50 μm and channel width (*W*) 1mm, have been fabricated using pentacene as the active semiconducting material and Rare Earth Oxide, Eu_2O_3 as the gate insulator in the bottom-gate, bottom-contact architecture on a perfectly cleaned glass substrates as shown in fig. 1.

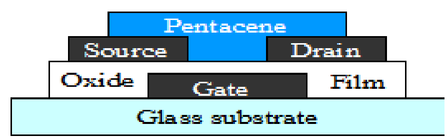

Fig. 1: Structure of the pentacene TFFET

Pentacene is a planar molecule and composed of five benzene rings fused along their sides, as shown in Fig. 2. It has triclinic crystal structure with two molecules in each unit cell. Several other pentacene polytypes also exist. They differ only slightly in their molecular packing and exhibit similar single-particle energy band gaps ~1.9 – 2.2 eV [5].

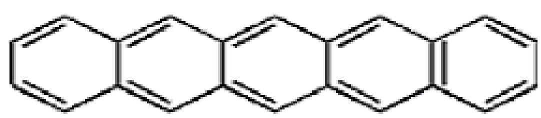

Fig. 2: Structure of the pentacene molecule

In Fig. 3, the structure of the fabricated OTFTs is shown. For the source–drain and gate electrodes aluminium (99.9% pure) is evaporated at a vacuum better than $7x10^{-6}$ Torr. The amorphous rare earth oxide film of Eu_2O_3 of 1480Å thickness (obtained from Loba Chemie in 99.99% pure form) is deposited to form the gate insulating layer. To form the active semiconductor layer, pentacene of 99.97% purity (obtained from Aldrich Chem. Co.) is thermally evaporated at a vacuum better than 4 x 10^{-6} Torr with a deposition rate of 0.5 Å/s. The TFFETs so prepared are annealed at 100ºC for 5 hours in vacuum (6 x 10^{-6} Torr) and the electrical characteristics are then measured.

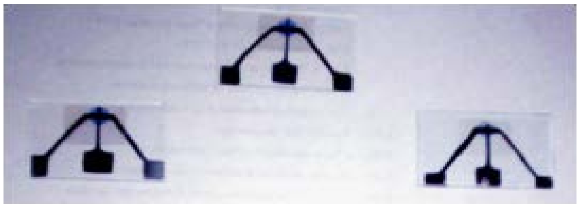

Fig. 3: Fabricated pentacene TFFETs

3. RESULTS AND DISCUSSION

In Fig. 4, the XRD pattern of the pentacene thin film deposited on glass substrate and without any annealing is shown. The observed diffraction peaks show that room temperature deposited thin film of pentacene is polycrystalline in nature. It is mainly due to the film deposition at ultrahigh vacuum conditions and at low deposition rate.

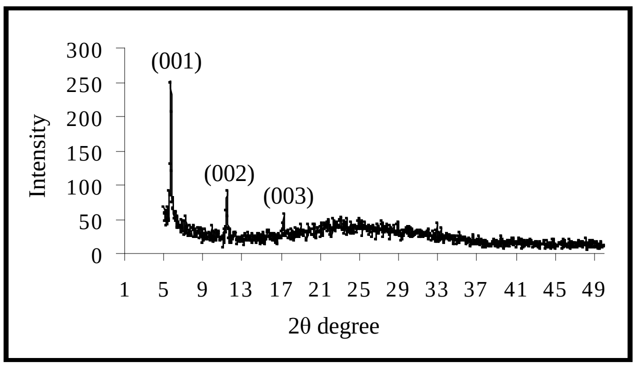

Fig. 4: XRD pattern of the pentacene thin film (not annealed) deposited on glass substrate.

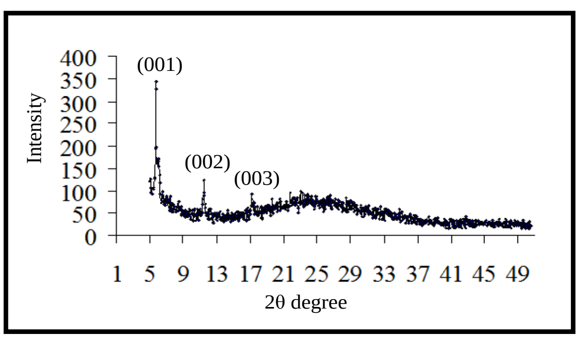

Fig. 5: XRD pattern of the pentacene thin film (annealed in vacuum at 100°C) deposited on glass substrate

In Fig. 5, the XRD pattern of the pentacene thin film deposited on glass substrate and annealed in vacuum at 100°C is shown. The Fig. shows that after annealing the intensity of diffraction maxima increases significantly. This suggests that the annealing of the pentacene films in vacuum increases the size of the crystallites (or grains) along the c-axis and also the defects in the film, due to disoriented crystallites, are eliminated [6].

The transistor characteristics curves, (plots of drain current I_D vs. source-drain voltage V_D at various gate voltages V_G), for the pentacene TFFETs (annealed in vacuum at 100°C) are shown in Fig. 6.

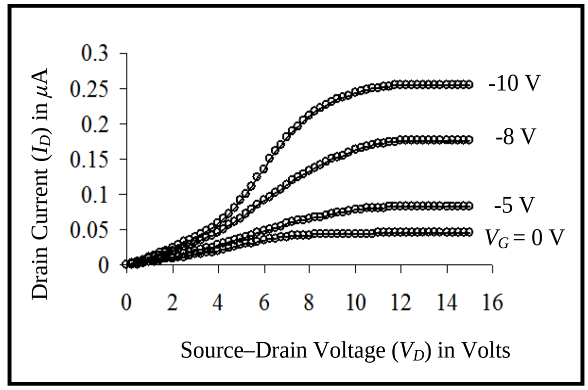

Fig. 6: Plots of drain current I_D vs. source-drain voltage V_D at various gate voltages V_G

From the characteristics it is observed that near the neighbourhood of the origin all the characteristics curves are 'S' shaped which is due to the blocking type of contacts between the semiconductor and the aluminium at the drain.

To evaluate different transistor parameters of the TFFETs, we follow the theoretical model proposed by Borkan and Weimer [7]. According to the Borkan and Weimer model the different transistor parameters such as, output resistance (r_d), transconductance (g_m), amplification factor (μ_A), drift mobility or the field effect mobility (μ_D) and the Gain bandwidth product ($G.Bw.$) of TFFETs can be evaluated and the equations from which the above parameters can be evaluated are given by.-

$$r_d = \left|\frac{\partial V_D}{\partial I_D}\right|_{V_G = const.} \quad (1)$$

$$g_m = \left|\frac{\partial I_D}{\partial V_G}\right|_{V_D = const.} \quad (2)$$

$$\mu_A = g_m r_d \quad (3)$$

$$g_m = \frac{\partial I_D}{\partial V_G} = \frac{\mu_D C_G V_D}{L^2} \quad (4)$$

$$G.Bw \approx \frac{g_m}{2\pi C_G} \quad (5)$$

Where C_G is the gate capacitance and L is the channel length.

In our fabricated TFFETs, the gate capacitance C_G is found to be 0.52 nF and L = 50 μm. Using these values and applying the above equations we have calculated the different transistor parameters of our fabricated devices, which are listed in table 1.

Table 1: Transistor parameters of the pentacene TFFETs with Eu_2O_3 as gate insulator.

Parameters	Calculated values of OTFTs
r_d (at constant V_G = -5V)	17.2 $M\,\Omega$
g_m (at constant V_D = 5V)	0.09 μ mho
μ_A	1.55
μ_D	0.71 x 10^{-3} $cm^2V^{-1}s^{-1}$
G.Bw.	27.14 Hz

From the above calculated TFFET parameters, it is observed that the output resistance of the fabricated devices is very high (in the mega ohm range). The amplification factor is also low.

The mobility value is higher than those obtained by Yasuda *et al*., (about 4.5 x 10^{-4} $cm^2V^{-1}s^{-1}$), with Calcium source-drain electrodes and polymeric gate insulator [8]. But these calculated values of mobility are low by about two orders of magnitude over the case of gold source-drain electrodes, as obtained by Lin *et al*. [9]. Further these values are found to be low by three orders of magnitude over the palladium source-drain electrodes and with SiO_2 as the gate insulator, obtained by Gundlach *et al*. [10]. This decrease in mobility is apparently due to the large barrier for carrier injection from aluminium to pentacene.

The performance of the TFFET in high frequency is characterized by its Gain bandwidth product and since its value is found to be very small so we can say that pentacene based organic TFFETs are not suitable in applications requiring very high frequency.

To estimate the grain size and trap density of the semiconductor film, we have applied the theoretical model proposed by Levinson *et al*. [11]. Using this model we have estimated a trap density of 5.5 x 10^{12} cm^{-2} in our semiconductor films and the average size of the grains is found to be 112Å.

4. CONCLUSION

In conclusion we can say that rare earth oxides are the promising gate dielectric material for organic TFFETs. With rare earth oxides as an insulating material, fabrication of pentacene based organic TFFET is possible and ideal transistor behaviour can be realised. Various parameters evaluated in this work give good understanding about the TFFET structure. However the transistor parameters for these devices are not so encouraging due to the presence of high trapping states. Hence for better performance further improvement in the quality of the semiconductor film is required.

5. ACKNOWLEDGEMENT

This work is supported financially by University Grants Commission, New Delhi, India, under Major Research Project.

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