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A Study On Gamma Radiation Effects On OTFT

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Abstract

The so-called Flexible, Large Area Organic Electronics (FOLAE) is expected to be one of the next big market hits, and it is, in fact, foreseen (IDTechEx) that will reach around 50 billion € in 2022 [1]. One of the key areas to reach this scenario is that of modelling and characterization of the behaviour of the organic devices.
Some compact models for organic thin film transistors (OTFTs) have already been developed [2-6] and tested, and are already included in some simulation tools [7]. The huge variations which are quite common in FOLAE have been given some attention to study their causes and effects [16].
Referred to the interaction with the environment, attention has been paid to factors like humidity, temperature, or illumination, but only a slight attention has been paid to factor like ionizing radiation. Ionizing radiation is a well known [17] agent modifying the behaviour of organic semiconductor. In fact, the standard total dose personal monitors are usually based on small tags of PMMA, which is widely as dielectric to fabricate FOLAE devices. However, only slight attention has been paid to these factors, and mainly to active devices (OTFTs [8] and OLEDs [9]), and to organic solar cells [10].
Following the work presented in [8], we can focus our study in the effects of the gamma-ray radiation. We will concentrate in two of the most important aspects for device modeling: the threshold voltage, and the mobility.
The change in the threshold voltage (ΔV_{th}) can be modelled in a very similar way to MOSFET transistors [11], and can be related to the increase of the trapped charges in the dielectric (Q_{dt}) and in the Interface State (Q_{it}) :

$$\Delta V_{th} = -\frac{\Delta Q_{dt} + \Delta Q_{it}}{C_i} \qquad (1)$$

where C_i is the gate capacitance per unit area. The net charged trapped in the dielectric layer after radiation is always positive. The charge trapped in the interface can exchange charge freely with the substrate, and thus their charges depend upon the bias applied to the device. In normal operation trapped charge is positive in a p-type transistor and negative in the n-type. Therefore, the threshold voltage of a p-type transistor shifts monotonically negative as the radiation dose increases. Equation (1) can be related to the total dose in a simple way, for low doses:

$$\Delta V_{th} = \frac{-1}{C_i}\left(\eta_1 d + \eta_2 d^2 + \ldots\right) \qquad (2)$$

where η_x are coefficients that will depend on the exact geometry of the transistor, the absorption of the different layers and their thickness, the energy of the incident radiation, etc., and is best determined experimentally.
The mobility of carriers in the transistor channel is degraded as the radiation dose increases. This leads to a reduction in transistor transconductance. The mobility degradation is caused by contribution of interface-trapped charge and dielectric-trapped charge., as well as a change in the HOMO-LUMO levels. If we use the model in [2], the mobility is modelled as:

$$\mu_{FET} = \mu_0 P(T, T_o) \frac{C_i^{\gamma}}{\epsilon^{\gamma/2}} (V_{GS} - V_{th})^{\gamma} \qquad (3)$$

$$P(T, T_0) = \frac{q k_b T N_V \exp\left(-\frac{E_{F0} - E_V}{k_b T}\right)}{\left(\pi q k_b T g_{d0} \exp\left(-\frac{E_{F0} - E_V}{k_b T_0}\right)\right)^{\gamma/2-1}} \cdot \left(\sin \frac{(\pi T / T_0)}{2 k_b T_0}\right)^{\gamma/2-1} \qquad (4)$$

$$\gamma = 2\left(\frac{T_0}{T} - 1\right) \qquad (5)$$

where k_b is Boltzmans constant, q is the electron charge and ε_s is the dielectric constant of the polymeric semiconductor. T_o is the characteristic temperature and g_{do} the density of localized states at valence band, described by an exponential type distribution. N_V is the valence band state density, and μ_o is taken to be one and used only for dimensional purposes. As can be seen in the expression, it undergoes through a very complex change in the behavior. Nevertheless, we can approximate this change in behavior using the same approach than for the threshold voltage:

$$\mu_{FET}(d) = \mu_0 P'(T, T_o, d) \frac{C_i^{\gamma(d)}}{\epsilon^{\gamma(d)/2}} (V_{GS} - V_{th})^{\gamma(d)} \qquad (6)$$

$$P'(T, T_{0,} d) = P(T, T_0)\left(1 + \kappa_1 d + \kappa_2 d^2 + \ldots\right) \qquad (7)$$

$$\gamma(d) = \gamma(d=0) \cdot (1 + \nu_1 d + \nu_2 d^2 + \ldots) \qquad (8)$$

where, as before, κ and ν are coefficients that depend on the same kind of factors than the threshold voltage coefficients. It has to be noted that the variation of $P(T,T_0)$ is affected by the variation of γ, so it can be expected a bigger change in the observed value of the mobility than the change in the γ exponent.

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