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Chapter

Tackling the Problem of Dangerous Radiation Levels with Organic Field-Effect Transistors

Irina Valitova, Zhihui Yi and Jonathan Sayago

Abstract

Accurate, quantitative measurements of ionizing radiation, commonly employed in medical diagnostic and therapeutic applications are essential prerequisites to minimize exposure risks. Common examples of radiation detectors include ionization chambers, thermoluminescent dosimeters, and various semiconductor detectors. Semiconductor dosimeters such as p/n type silicon diodes and MOSFETs have found widespread adoption due to their high sensitivity and easy processing. A significant limitation of these devices, however, is their lack of tissue equivalence. The high atomic number (relative to soft tissue) of silicon causes these devices to over-respond to photon beams that include a significant low energy component, for example, 1–10 kV, due to an enhanced photoelectric interaction coefficient. Organic field effect transistors (OFETs) are capable of providing tissue equivalent response to ionizing radiation in order to monitor more accurately the risk of exposure in medical treatments. This chapter presents the possibility to use different types of OFETs as ionizing and X-ray radiation dosimeters in medical applications.

Keywords: OFET dosimeters, ionizing radiation, X-ray detection, ion sensors, ionizing radiation dosimeters, radiation dosimeters

1. Introduction

Since the beginning of research in both radiotherapy and X-ray imaging, an attempt has been made to measure the cumulative exposure to radiation that could be harmful to the patient. Ionizing radiation is related to heavy charged alpha- and beta- particles, also X-rays which are highly energetic electromagnetic waves (light), can interact with matter to produce secondary ionizing radiation which can result in health issues. This is particularly the case in medical screening procedures such as mammography, tomographic, and nuclear imaging [1].

The need for high precision radiation monitoring is particularly important in radiotherapy. Approximately half of all patients diagnosed with cancer receive some form of radiotherapy over the course of their treatment [2]. In radiotherapy, a precise dose of radiation is delivered to control or eliminate the disease in neoplastic tissue but not large enough to incur in significant risk to damage healthy tissue. In such cases the risk of the procedure has to be carefully balanced against the expected benefits. Therefore, accurate dosimetry is needed to deliver successful radiotherapy.

Ionizing radiation sensors are devices that respond to ionic radiation and output a proportionally strong electrical or optical signal. To understand the performance of a sensor it is important to have an understanding of how the signals are generated and recorded.

The main quantities of dosimetry will be introduced in this chapter as well as the basic OFET sensing mechanism and a review of the most prominent research up to date in the field.

1.1 Sources of ionizing radiation

The source of ionizing radiation can originate from radiation generators (accelerators of charged particles and nuclear reactors), radioactive materials and electromagnetic radiation. The maximum attainable energy and intensity of ionizing radiation beams are related to the source of radiation. For example, cobalt-60 isotope emits gamma rays with energies of the gamma quantum at 1.17 and 1.33 MeV [3]. The radiation from radioactive materials has an energy spectrum that changes as a function of time due to the short half-life of some radioactive isotopes.

Sources of electron- or beta- rays can be different types of electron accelerators with energies ranging from several tens of MeV. Commonly used accelerators are the Van der Graff generators, linear accelerators and cyclotrons.

Electromagnetic radiation, X- and gamma rays, have the highest energy photons (light) in the electromagnetic spectrum and concern biomedical sensors because they can attain energies of 1 kV to 25 MeV, large enough to interact with its medium to form secondary charged particles that can be detected in a dosimeter.

1.2 Exposure, dose and dose equivalent

An ionizing radiation beam can be characterized by its exposure, which is the ratio of charge it creates in its medium to the air mass (SI: C Kg^{-1}). For convenience, the medium is air because air has an atomic number of 7.6, which is tissue equivalent (tissue has an atomic number of 7.4). The SI unit is the coulomb per kilogram, however, historically a common unit of measure is the roentgen (R). One R equals 0.000258 C Kg^{-1}.

The absorption characteristic of the target material (i.e. skin tissue) results in the concept of absorbed dose. The absorbed dose is the amount of energy absorbed per unit mass of target material (SI: J Kg^{-1}), as a result of an exposure to ionizing radiation. Common units of measure for absorbed dose are the rad, the gray (Gy) and the erg; 1 rad = 0.01 Gy = 0.01 J Kg^{-1} = 100 ergs g^{-1}.

In other terms, exposure refers to the radiation in an area and the dose is the amount of that radiation is expected to be absorbed by a person or a target material. For a given radiation source, the absorbed dose will depend on the matter that absorbs the radiation. For example, for an exposure of 1 R of gamma rays with an energy of 1 MeV, the dose in silicon will be 0.88 rad and the dose in human tissue will be 1 rad [4].

The absorbed dose itself is ineffective for describing the biological effects of radiation, in which, to a close approximation an equal amount of absorbed energy corresponds to an equal amount of damage [4]. For this purpose, the dose equivalent was defined, as the product of the absorbed dose times the radiation weighting factor taking into account the beam type. **Table 1** summarizes the weighting factor (w) for different types of radiation [5].

Although w is dimensionless, the unit employed to define dose equivalent is not the same than that for dose (Gy) but is the sievert (Sv): 1Sv = 1 J Kg^{-1}. People at risk for repeated ionizing radiation exposure are commonly monitored and restricted to effective doses of 100 mSv every 5 years with a maximum of 50 mSv allowed in any given year [6].

Type of radiation	Weighting factor (w)
Photons	1
Electrons	1
Neutrons	
<10 keV	10
10–100 keV	20
>100 keV to 2 MeV	10
>2–20 MeV	5
>20 MeV	5
Protons, energy >2 MeV	5
α-particles	20

Table 1.
Radiation weighting factor (w) for different types of radiation beams [5].

1.3 Interaction of ionizing radiation with matter

Ionizing radiation can be classified into heavy- protons, ions- and light charged particles- electrons and positrons. The type of radiation clearly modifies its interaction with matter. As one would imagine, a heavy charged particle has a larger mean range or penetration depth than lighter particles. Both particles can loose energy through collisional or radiative energy transfer [5]. The first mechanism dominates in heavy particles and the latter is mainly present in electrons passing through high-Z materials.

Most biomedical sensing applications involve collision dissipation of low-energy ion beams (i.e., 10 keV) thus the penetration depth upon collision is relatively low yet the thickness or volume of the sensing material should be large enough to ensure that most energy associated with the ionizing particle is deposited within the active layer. Of course, the penetration depth also depends on the material the beam is interacting with.

The four most common interaction types are Rayleigh scatter, photoelectric effect, Compton scatter, and electron-positron pair production [7]. The main photon- medium interactions are in the energy range from 100 kV to 18 MV (produced by medical accelerators for cancer treatment) are the photoelectric effect and Compton scattering. Rayleigh scattering and pair production are responsible for a lower percentage of photon interactions.

Rayleigh scattering is a process where a photon interacts with an orbital electron in the medium and deflects through a very small angle. The angle of deflection is proportional to the energy loss. So the Rayleigh scattering is an elastic process, meaning that very small amount or no energy is lost by the scattered photon.

The mass attenuation or extinction coefficient for Rayleigh scattering, σ_R/ρ, depends on the energy of the photon and the atomic number of the material through which the photon is traveling:

$$\sigma_R/\rho \propto Z/E^2, \tag{1}$$

where E is the energy of the incident photon and Z is the atomic number of the medium. Pair production occurs when the photon passes close to the nucleus of the atoms and if the energy of photon is high enough (>1.022 MeV) an electron and positron pair will be created. The mass attenuation coefficient for pair production, κ/ρ, depends on the atomic number of the material through which the photon is traveling: $\kappa/\rho \propto Z$.

The Compton collisions become predominant when the photon energy becomes significantly larger than the binding energy of electron (i.e., 50 keV and above). The photon transfers part of its energy to the electron and scatters.

The photoelectric effect occurs when a photon's energy exceeds the binding energy of the electron on its shell. In this case, the electron gets ejected from the atom with a kinetic energy equivalent to the incident photon energy minus the binding energy of the electron. This photoelectric current (the number of photoelectrons) strongly depends on the atomic number Z of the target, while Compton effect does not. This is why the photoelectric current from high Z materials is higher than that of tissue equivalent materials with lower Z (7.4).

Commonly employed sensing materials are high-Z (high atomic number) which include carbon, silicon, germanium, cesium iodide, sodium iodide. However, they have limitations in the processing of large area pixelated sensor matrices due to the relatively low resolutions achievable with these devices and their low life cycles due to structural defects caused in the sensing material by the ionizing radiation beam.

2. Detectors of ionizing radiation

A dosimeter is a device that measures dose uptake of ionizing radiation beams. The response of an ideal dosimeter should be: linear with the absorbed dose and consistent over time; directly proportional to the dose and independent of the type of radiation and its energy; independent of the pulsed and continuous dose rates and independent of the average dose rate; proportional to the absorbed dose and independent of the incident radiation angle; reproducible and stable [5].

There are a few standard methods for determining the exposure or absorbed dose [4]. The calorimetric method, or thermodynamic method, measures the total heat generated during the absorption of energy from a radiation field. Alternatively, an ionization chamber can be used to measure the number of ions produced in air (or other gases) by charged particles or electromagnetic radiation. The device is fairly simple; it essentially consists of two electrodes in a gas-filled space in which the incident radiation produces ionization. A voltage applied between the two electrodes draws the ions to them and the resulting current flow is measured.

When measuring high energy radiation (MeV), chemical changes in matter (polymerization, oxidation, reduction, degradation) as well as physical changes in material properties (color) as a result of radiation, can be used to quantify radiation. The best example is the viscometric dosimeter that measures the change in molecular structure of polymethylmethacrylate polymer as it degrades upon radiation. The degradation results in a decrease of its average molecular weight which then can be measured by dissolving it and determining the solution viscosity. Another good example is the glass dosimeter in which high doses of radiation produce measurable darkening of the glass by the formation of absorption bands in the electronic structure of the material. Changes in the optical properties are determined with a spectrophotometer and compared with an unexposed reference glass [8]. Polyethylene releases hydrogen under irradiation, which in turn can increase the relative pressure of a sealed chamber providing a cost-effective and versatile dosimeter solution (in terms of the sensor location, close or far away from the source) for high dose sensing.

One difficulty of employing organic materials as sensing material is the requirement of a thick layer of material to absorb a significant portion of the radiation because the exposure is a function of the source location. The use of the viscometric dosimeter has the advantages of using organic tissue-equivalent material as sensing material and being cost-effective simple solution, however the accuracy is only about 20%.

2.1 Solid-state methods for sensing ionizing radiation

Solid-state dosimeters are well established today. They commonly employ inorganic semiconductors with a small number of impurities as the sensing material.

On one hand, ionizing radiation induces electronic states (traps) at intermediate energies between the valence and conduction bands of the semiconductor. If the trap energy levels are large enough to produce light when excited electrons decay, the characteristic light emitted through this process is proportional to the number of traps and thus, proportional to the dose absorbed by the material upon ionizing radiation. An external source of light can be applied to excite electrons from the valence band to the conduction band, see **Figure 1**, and a spectrophotometer can be used to detect the light emitted from the photon as it decays through the trap.

2.2 MOSFET sensors

Metal oxide semiconductor field-effect transistors are well known and have been used for decades as dosimeters. They consist of a semiconducting channel sandwiched between drain and source electrodes (electricity can be thought of as water flowing through a pipeline) and switched on/off by a gate consisting of a dielectric and a third electrode, **Figure 2**.

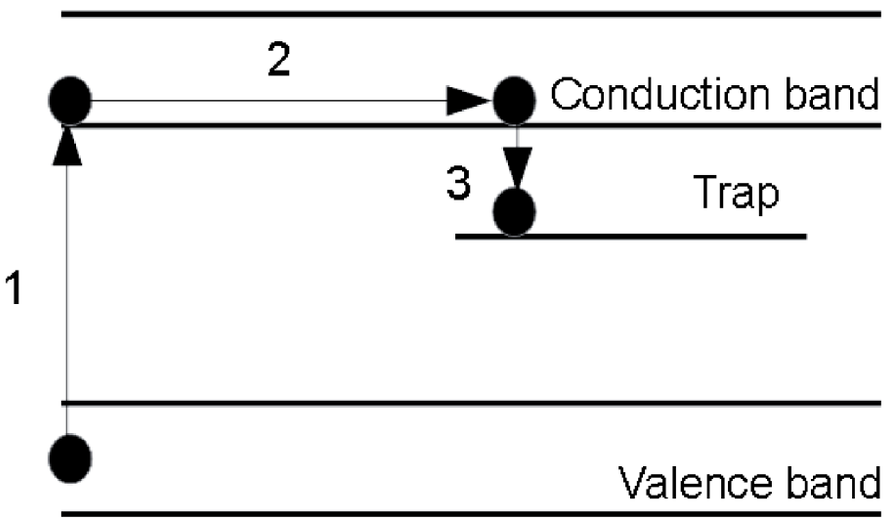

Figure 1.
Optically stimulated luminescence for dosimetry: An electron (1) is excited by a light source into the conduction band, (2) migrates through it and (3) falls into a trap emitting a characteristic light proportional to the number of traps previously induced by ionizing radiation.

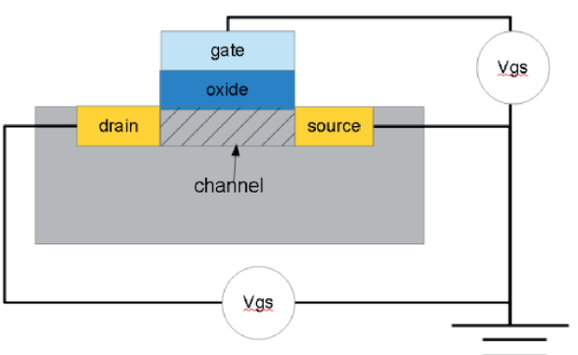

Figure 2.
A metal oxide semiconductor field-effect transistor typical structure.

The flow of current between drain and source electrodes is limited by the number of charge carriers available in the semiconductor channel. Applying a gate voltage polarizes the dielectric material and results in the accumulation of charge carriers at the interface between the semiconductor and the dielectric thus increasing the conductivity in that region (field-effect). Transistors are typically characterized by the threshold voltage one must apply to the gate to switch on a drain-source current. When the device is exposed to ionizing radiation, a fraction of the charge carriers are trapped in the oxide-substrate interface creating an electric field that increases the value of the threshold voltage. The variation in threshold voltage is therefore directly proportional to the traps created in the semiconducting channel by the delivered dose.

A slight variation of the MOSFET dosimeters can be found in p-n or p-i-n diodes in which the degradation of the semiconductor by ionizing radiation results in differences in time-resolved photoconductivity.

Commonly utilized materials in solid-state dosimeters are LiF in combination with Mg, Cu, P and Al_2O_3, for low-dose dosimetry [9, 10]. Sodium iodide doped with thallium (NaI:Tl) is probably the most used dosimeter for gamma detection [11].

The advantages of solid-state dosimeters include high sensitivity, high reproducibility and linearity over a wide range. However, their main disadvantage is related to the lack of tissue equivalence.

3. Organic electronics and their relevance for tissue equivalences

In order to track correctly the mechanisms of energy release in skin tissue, the ideal dosimeter must be tissue equivalent, with a Z as close as possible to 7.4. At high energy sensing, tissue equivalence may be even more relevant due to the changes in the effective cross section particle interaction with the target originated from resonance peaks in elastic scattering [5]. In tissue equivalent sensors, the mass stopping power of the target varies slowly as a function of the electron energy, therefore, there are no sharp peaks commonly observed with resonances with high-energy particles and high Z materials.

Organic electronics, based on *soft* materials, have gained interest in radiation dosimetry for tissue equivalent applications. The low atomic number of organic materials is comparable to that of average human soft tissues, which suggests that these devices may require fewer or smaller correction factors to translate a measured signal into a dose absorbed by skin tissue under conditions that deviate significantly from calibration conditions. These devices offer other advantages over their inorganic counterparts, namely—their versatility, mechanical flexibility, solution processability, low cost and suitability for large and nanoscale applications.

Changes of both electronic and optical properties of organic materials under irradiation can be used for high accuracy dosimetry. The shift of organic polymers absorbance or reflectance allows visualizing structural defects due to ionizing radiation [12], and electronic changes can be detected in different device configurations, such as capacitors, diodes and Organic Field-Effect Transistors (OFETs) [13–15].

A radiation-induced changes in the electronic properties of insulating polymer materials like poly(methyl methacrylate) (PMMA), polystyrene (PS) or polyethylene has been known for decades [16] in which the radiation-produced free electrons trapped in the band gap are thermally released into the conduction band under the radiation field. Later the use of organic semiconducting polymers helped to improve the dosimeter sensitivity due to the better charge carrier mobility and better carrier lifetime. The use of organic polymers in different organic electronic devices such

as organic diodes and Organic Field-Effect Transistors (OFETs) with the tissue equivalence that we previously discussed will be introduced further.

3.1 Dosimetry based on organic field-effect transistors

Various parameters, such as off current, on current, threshold voltage V_{th}, current ratio and subthreshold swing, can be extracted as a function of ionizing radiation dose from the measured transfer characteristics of organic field effect transistors. Raval et al. introduced bottom gate top contact OFET with P3HT as semiconductor on a silicon dioxide (SiO_2) dielectric layer as radiation dosimeter. After ϒ-irradiation up to 41 krad using a Co-60 radiation source, they found a decrease in the on current by a factor of 2, an increase in off current by a factor of 150, and a decrease in the mobility. The threshold voltage was shifted negatively due to positive charge accumulation in the silicon dioxide [17]. Later the same group investigated Pentacene OFET using similar device structure shown in **Figure 3**. The silicon nitride as a passivation layer was used to protect organic materials from

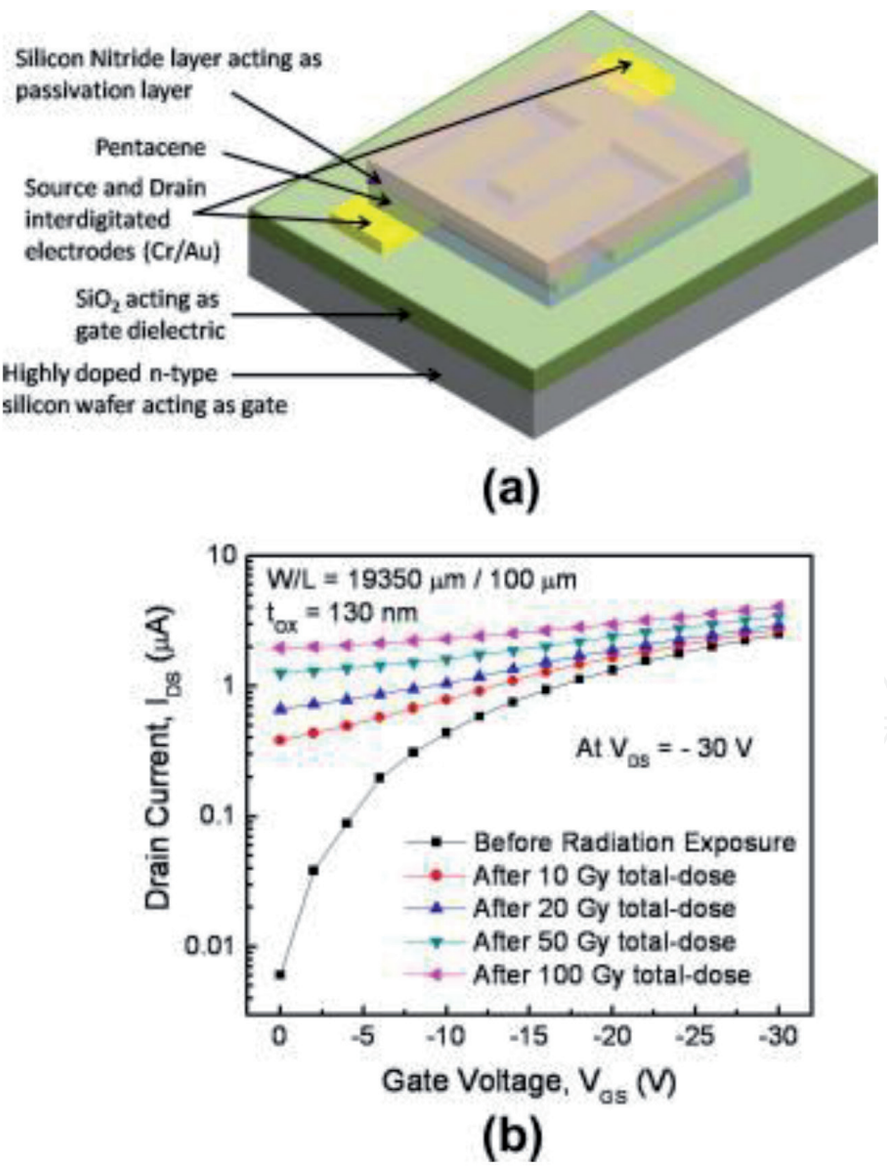

Figure 3.
(a) Schematic of a pentacene OFET in bottom gate bottom contact configuration with interdigitated source and drain electrodes using a silicon nitride passivation layer, and (b) I_d-V_g characteristics for a Pentacene OFET with exposure to increasing dose of ionizing radiation [18].

interaction with air. After exposure to a total of 100 Gy dose of ionizing radiation off current was increased 320 times which resulted in a sensitivity of 20 nA/Gy. The threshold voltage shift resulted in a sensitivity of 0.3 V/Gy [18].

Furthermore, they introduced CuPc OFET dosimeter after γ-irradiation with a minimum dose of 10 rad going up to a maximum dose of 100 krad. To solve the resolution limitation of measuring the off current for less than 1 krad total-dose exposure three and five OFETs were connected in parallel. The transfer characteristics of those sensors after different total-dose exposures to γ-radiation are shown in **Figure 4**. The measured sensitivity from off current shifts after irradiation was

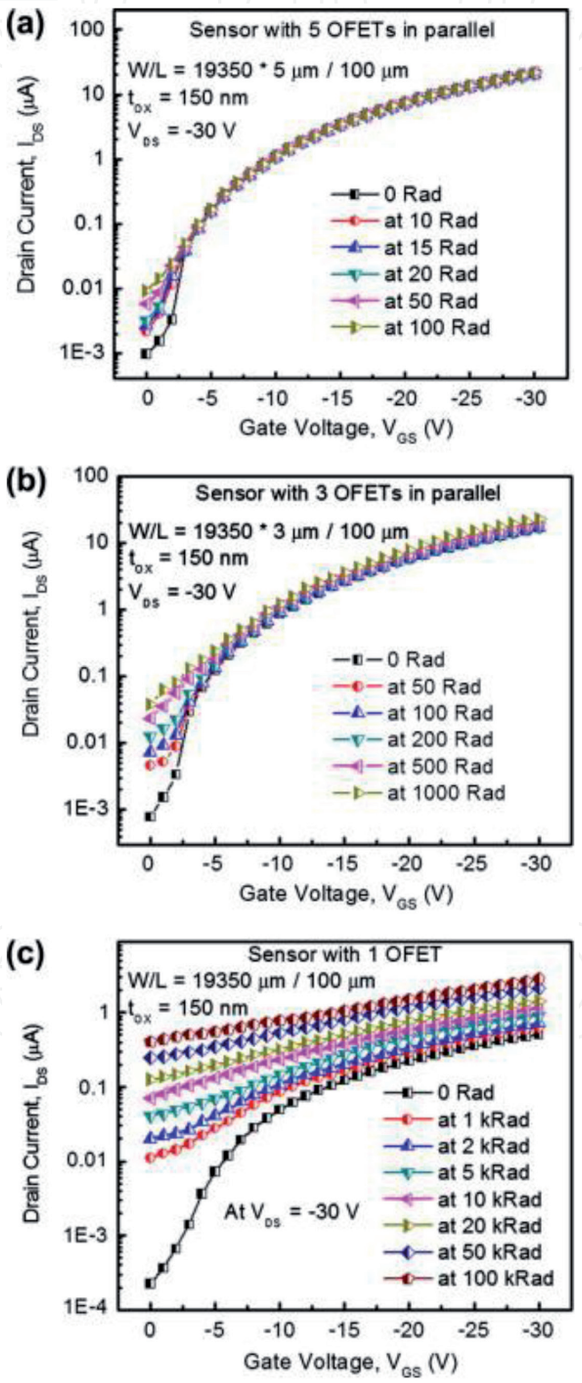

Figure 4.
(a) Transfer characteristics for a sensor with five CuPc-OFETs each with W/L = 19,350 lm/100 lm stacked in parallel for total-dose exposures up to 100 rad with the minimum dose of 10 rad. (b) Transfer characteristics for a sensor with three CuPc OFETs each with W/L = 19,350 µm/100 µm stacked in parallel for total-dose exposures up to 1 krad with the minimum dose exposure of 50 rad. (c) Transfer characteristics for a CuPc OFET sensor with W/L = 19,350 µm/100 µm exposed to a minimum of 1 krad, and with increasing total-dose exposures up to 100 krad [19].

of 0.02 A/rad. From the V_{th} shift measured at constant drain current $1e^{-7}$ A the sensitivity of 1.5 10^4/rad was observed for a total of 100 krad dose-exposure [19].

Kim et al. introduced a rubrene semiconductor OFET as a dosimeter to electron beam irradiation [15]. To show that radiation induced charges can be trapped not only in SiO_2 dielectric and Si/SiO_2 interface but also in organic semiconductor, they compared two sets of devices. In one set of devices they irradiated a silicon/silicon dioxide substrate before deposition of a rubrene semiconductor. The on and off currents were about the same while the mobility fell by about 50% after 10^7 rad in comparison to pre-irradiation conditions. A second set of devices was irradiated after the deposition of rubrene. The mobility decrease of more than 50% was found only after 10^5 rad dose exposure. Moreover, the subthreshold swing was decreased with increased radiation dose. So the charge trap density at rubrene/SiO_2 interface was increased as a function of radiation dose. They concluded that electrons could induce traps not only on interface but also in the bulk semiconductor.

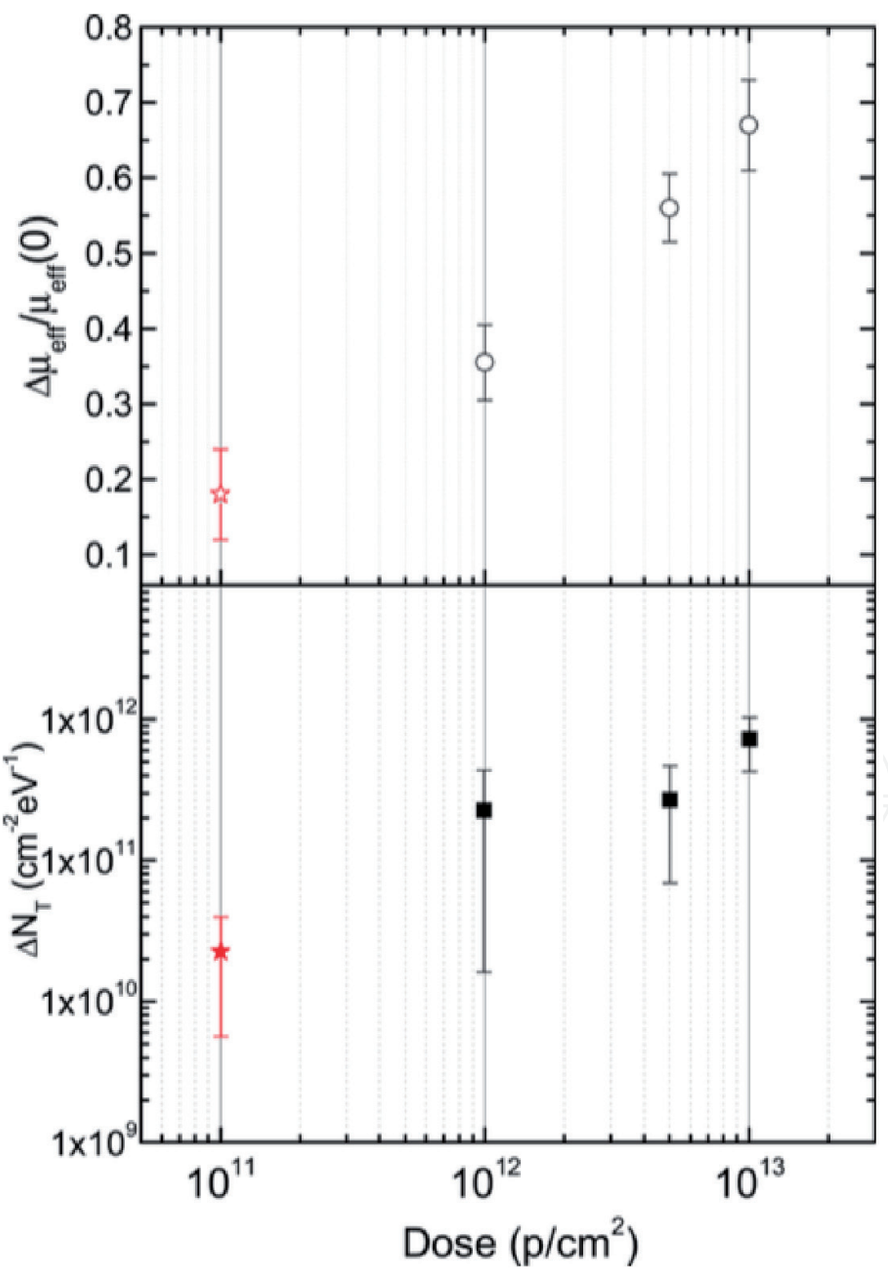

Figure 5.
Variation of the trap densities, ΔN_T (bottom solid squares), and of the channel mobility relative to $\mu_{eff}(0)$ and $\Delta\mu_{eff}/\mu_{eff}$ (0) (top open circles) as a function of the irradiation dose [20].

The reduction of charge carrier mobility proves that radiation induced density of traps also energetically located near the highest occupied molecular orbital of the organic semiconductor. However, Basirico and colleagues only partially related the reduction of charge carrier mobility with increase of charge carrier traps in 6,13-bis(triisopropylsilylethynyl)-pentacene (TIPS-pentacene)-based field effect transistors with organic dielectric irradiated by high energy protons [20]. The high energy protons induce defects in the organic dielectric and strains in the TIPS-pentacene layer leading to mobility reduction. The variation of trap densities and charge carrier mobilities as a function of radiation dose shown in **Figure 5**.

Jain et al. improved the response of OFET to radiation by mixing organic semiconductor with Polystyrene probably increasing the amount of trap carrier density. TIPS-Pentacene (TP) and Polystyrene (PS) blend as semiconductor material in OFET for sensing gamma rays from cobalt-60 (^{60}Co) radiation source [21]. The device configuration was n-type Si as a gate electrode, 100 nm of SiO_2 as a gate dielectric layer, TP/PS blend as semiconductor and interdigitated Au source/drain electrodes on the top. Devices irradiated before deposition of TIPS-Pentacene and devices irradiated after deposition of semiconductor were compared to show the amount of charges trapped in TP/PS blend and in the SiO_2/TP-PS interface. It was shown that interface trap density of SiO_2/TIPS-Pentacene was significantly higher in irradiated TIPS-Pentacene than trap density of devices irradiated before TIPS-Pentacene deposition. The sensitivity of TIPS-Pentacene transistors was highest among similar organic transistors in the literature, 3 V/Gy [21].

3.2 Dosimetry based on organic diodes and single layered structures

Boroumand et al. reported the tissue-equivalent direct response of organic semiconducting polymers, such as poly(2-methoxy-5-(2′-ethylhexyloxy)-p-phenylene vinylene) (MEH-PPV) or poly 9,9-dioctylfluorene (PFO), to 17 keV X-rays from a 50 kVp molybdenum source. In order to maximize the X-ray photon attenuation, the typical polymer film thickness was approximately 20 μm. The sensitivities of the devices at −10 V applied bias were 0.064 nC/mGy for PFO and 0.1 nC/mGy for MEH-PPV, and 0.24 nC/mGy at −50 V for PFO. These values correspond to sensitivities per unit volume of 128–480 nC/mGy/cm^3, which are similar to silicon-based devices [22].

Flexible dosimeters incorporating a ~ 10 μm poly([9,9-dioctylfluorenyl-2,7-diyl]-co-bithiophene) (F8T2) film were fabricated on a polyimide substrate [23]. The higher electric field in these devices helped to separate X-ray-generated charge carriers leading to increase the sensitivity from 54.2 to 158.2 nC/mGy/cm^3 when reversed applied voltages were −10 and −50 V, respectively.

Intaniwet demonstrated the influence of charge carrier mobility in organic semiconductors on the dosimeter sensitivity [24]. The blend of high mobility 6,13-Bis (triisopropylsilylethynyl)pentacene (TIPS-pentacene) with conjugated polymer poly(triarylamine) (PTAA) was used to improve the sensitivity of organic dosimeters to detect up to 17.5 keV X-rays from a molybdenum source. The PTAA device with charge carrier mobility of $1.3*10^{-6}$ cm^{2}V^{-1} s^{-1} possessed a sensitivity of 116 nC/mGy/cm^3 and the TIPS:PTAA blend (17:1) with mobility $19*10^{-6}$ cm^2/Vs had four times more sensitivity, up to 457 nC/mGy/cm^3. The sensitivity of organic semiconducting single crystal (OSSC) dosimeters did not appear to depend on the charge carrier mobility. For example, it was shown that the high mobility single crystal ruberene possessed poorer X-ray sensitivity than the low mobility DNN (1,5-dinitronaphthalene) [25].

Another important factor known to affect organic based dosimeters is the morphology of the semiconducting film. Dr. Fraboni studied the influence of anisotropic π-π stacking of molecules and the photo-response when exposed to X-ray radiation [26]. They selected 1,5-dinitronaphthalene (DNN) as the active

material which has strong π-π stacking in one axis of the crystal and compared the results with 4-hydroxycyanobenzene (4HCB) with a more planar morphology. The photoconductivity increased almost linearly with the applied voltage bias to the crystal along the vertical axis while it tends to saturate along the planar ones even for driving voltages as low as 50 V with no hysteresis effect and considerable reproducibility and device life-cycles, indicating that OSSCs are promising candidates for direct X-ray radiation detection (**Figure 6**, left). They reported that the

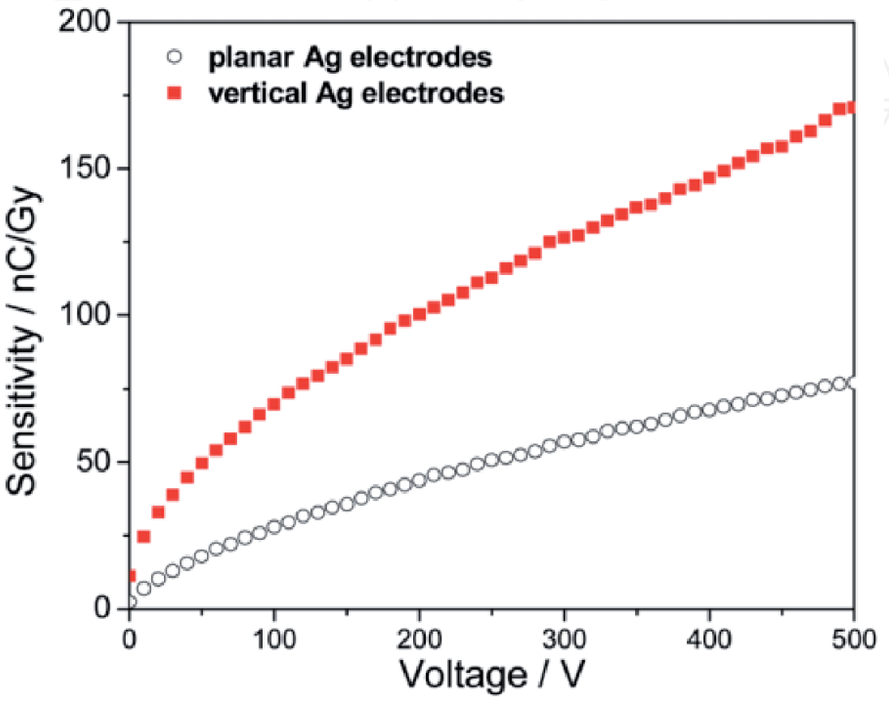

Figure 6.
Comparison between the sensitivity values at different bias voltages for a 4HCB- based detector under 35 keV X-ray irradiation in the planar (black circles) and vertical (red squares) electrode configuration [26].

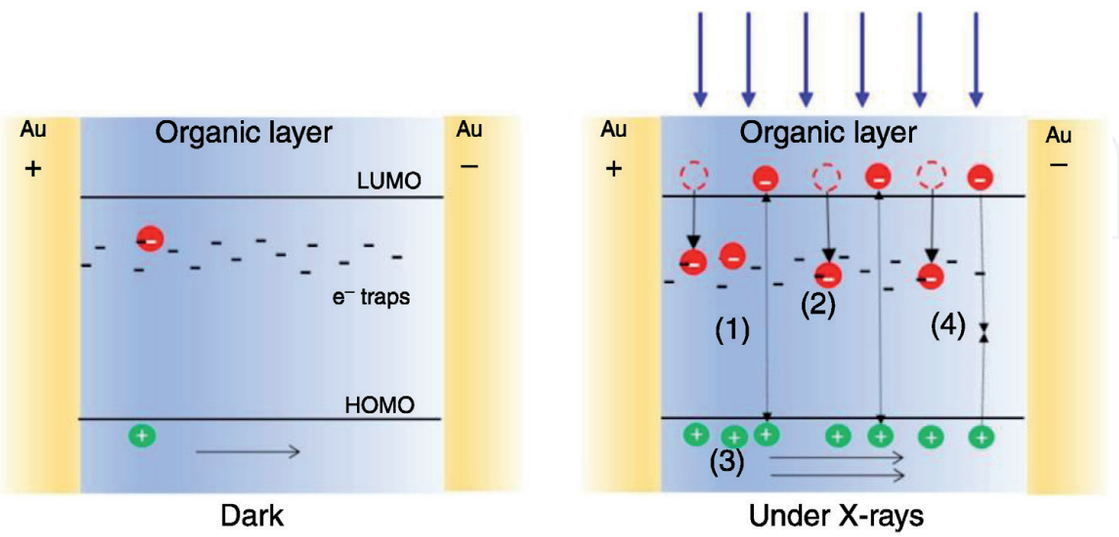

Figure 7.
Schematic of the process of modulation of the conductivity induced by X-rays exposure of TIPS-pentacene thin films: (left) in dark, the conductivity is mainly due to the intrinsic charge carriers; (right) under X-ray irradiation: (1) additional electrons and holes are created and holes drift along the electric field until they reach the collecting electrode while (2) electrons may remain trapped in deep trap states within the organic material. (3) to guarantee charge neutrality, holes are continuously emitted from the injecting electrode. For each electron–hole pair created upon radiation, more than one hole contributes to the photocurrent leading to a photoconductive gain effect. (4) recombination process takes place counterbalancing the charge photogeneration in the steady-state [28].

film thickness of crystals has minor influence on the sensitivity for a device with electrodes larger than 2 mm^2. The maximum obtained sensitivity for large electrode area samples is 175 nC Gy^{-1} [27].

Fraboni and co-workers proposed a model to explain the photocurrent signal induced by X-ray radiation (**Figure 7**) [28]. The model described the accumulation of holes in the LUMO level with the X-ray radiation. Radicals generated from the X-rays radiation activated energy levels within the HOMO and LUMO levels where electrons were trapped. The induced holes in the LUMO level induce an increase in the photoconductivity easily measurable due to the high sensitivity to X-rays and electrical response of the material.

4. Conclusions

Organic field effect transistors are new but very potential devices to be used as ionization radiation dosimeters. Different parameters like off current, on current, threshold voltage, current ratio and sub-threshold swing can be monitored as a function of ionizing radiation dose. Organic field effect transistors are capable of providing a tissue equivalent response to ionizing radiation. High Z counterparts, such as insulating layer and metal electrodes can be fabricated making use of organic dielectrics and conducting polymers (PEDOT:PSS or others), respectively. Moreover, organic materials possess outstanding properties, such as large area processing on lightweight and flexible substrates and ability to chemically tailor their properties. In particular, lightweight, flexible OFETs can be attached to the patient during the radiation treatment with possibility to read out parameters after treatment or operating transistors at very low voltages. For sure more work should be done on sensitivity improvement and characterization of such dosimeters. For example, it is important to check their linearity, energy and dose rate dependence, and so on. The sensitivity of such dosimeters can be improved by increasing the trap carrier density in organic semiconductor or dielectric layers. Similar to organic memory devices dielectric layer can be complex or with floating gate to store more charges and thus show the improved response to ionizing radiation.

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