Techniques to increase the sensitivity for dosimetry sensors

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Abstract. This work presents different techniques to increase the sensitivity of commercial MOSFET (no RADFET) to demonstrate their potential as dosimetry sensors with electrons beams (for IORT) and gamma radiation. Different models of commercial MOSFET were irradiated in unbiased and biased mode, to select the best candidate and configuration for each type of radiotherapy.

1 Introduction

In-vivo dosimetry during radiotherapy treatments can be carried out with different types of sensors, such as ionization chambers, thermoluminescent crystals, diodes and MOSFET (Metal-Oxide-Semiconductor Field Effect Transistor).

The radiotherapy treatments use electrons and photons beams (gamma radiation), depending on the depth of the tumor. For superficial tumors electrons beams are used, however for the deepest cancers, the photons treatment is more effective. In both cases the treatment is divided by several sessions of radiation. On the other hand, the intra operative radiotherapy (IORT) is a complementary technique used just after the cancer extraction. IORT aims to destroy the remaining tumor cells on the edge of the cancer using electron beams. The dose must be applied in only one session and just after the operation with the patient lying on the stretcher.

In the last few years, commercial dosimetry systems have been developed [1] based on MOSFET of P channel (pMOS), because they have a number of advantages over traditional dosimetry systems in medical applications. The most important are immediate and non-destructive readouts, low power consumption, easy calibration, and reasonable sensitivity and reproducibility [2].

The sensing principle is based on the radiation-induced electron-hole pairs in the gate-oxide of the transistor, which creates additional oxide trapped charge producing a threshold voltage shift, ΔV_T [4]. For increasing the sensitivity of the MOSFETs used in radiation, they are manufactured with special process in order to achieve a thick gate oxide. This type of MOSFETs is known as RADFETs and the cost is relatively high due to the reduce production volume.

This work presents different techniques to increase the sensitivity of low-cost commercial pMOS (no RADFET) to demonstrate their potential as dosimetry sensors with electrons beams and gamma radiation. The use of general purpose transistor will reduce the cost of the final system. The techniques consist on different configurations of polarization, because the pMOS polarization during radiation is also a crucial factor in sensor sensitivity. The pMOS transistor can be biased or unbiased during the radiation sessions. In the biased mode, a positive difference of voltage is applied and reducing the recombination probability of electron-hole pairs produced by the radiation in the gate-oxide and increasing the trapped charge creation [5]. The unbiased mode is characterized by no connections during radiation; usually all device terminals are short-circuited together.

2 Materials and methods

It is well known that the dose is nearly proportional to the shift of the threshold voltage, ΔV_T. To measure the increment of V_T, a reader unit, developed in the Department of Electronics and Computer Technology at the University of Granada, was used. This electronic system consists of a wireless sensor module containing a general-purpose MOSFET and a microcontrolled reader unit. Various methods, developed in previous works [6], to extend the linear range and reduce noise and thermal drift have been implemented in this measurement system. The instrument biases the transistors at one, two or three different currents sequentially, and measures the voltage source at these currents [6]. Three-currents method and two-currents method have been used in our case to measure the ΔV_T. In the three-currents method the thermal modeling of the MOSFETs is required [3].

Three models of commercial MOSFETs have been tested: CD4007 (manufactured by Texas Instruments) for electrons beams, 3N163 (Vishay Siliconix) for photon and the ZVP3306 (manufactured by Zetex Semiconductors) for both types of beams. All models are pMOS transistor. A total of fifteen transistors per model were irradiated. The CD4007 MOSFETs were irradiated with electrons of 6 MeV in session from 1.42 Gy to 14.20 Gy with a field of 25x25 cm^2 and 1.42 Gy per radiation session. The 3N163 were irradiated with photons beams of 6 MeV with 1.94 Gy per radiation session up to 13.58 Gy, from 7.76 Gy with a field of 10x10 cm^2. The ZVP3306 transistors were irradiated with gamma radiation of 6 MeV with 1.9 Gy per radiation session up to 9.5 Gy with a field of 10x10 cm^2, and electrons beam with 6 MeV too, with sessions up to 8.40 Gy with field of 25x25 cm^2 and 1.40 Gy per radiation.

All of them were placed at the isocentre of the source (at 100 cm) with normal angle of incidence. Each model was irradiated in biased and unbiased mode. For the photons beams, it was used 1 cm of solid water above the MOSFET, to ensure the electronic equilibrium conditions. The accelerators used were LINAC Siemens Mevatrons KDS for electrons and an AECL Theatron 780 for gamma beams, both located at the University Hospital “San Cecilio” in Granada (Spain).

In all the cases, the sensor module consists of the MOSFETs and one or two JFETs, in unbiased and biased mode respectively. The configuration can be observed in the Figure 1. The JFETs transistors are cut off or on, which depends on the radiation process or readout process of V_T. In all the cases during the readout process of V_T the transistor operates in the saturation region.

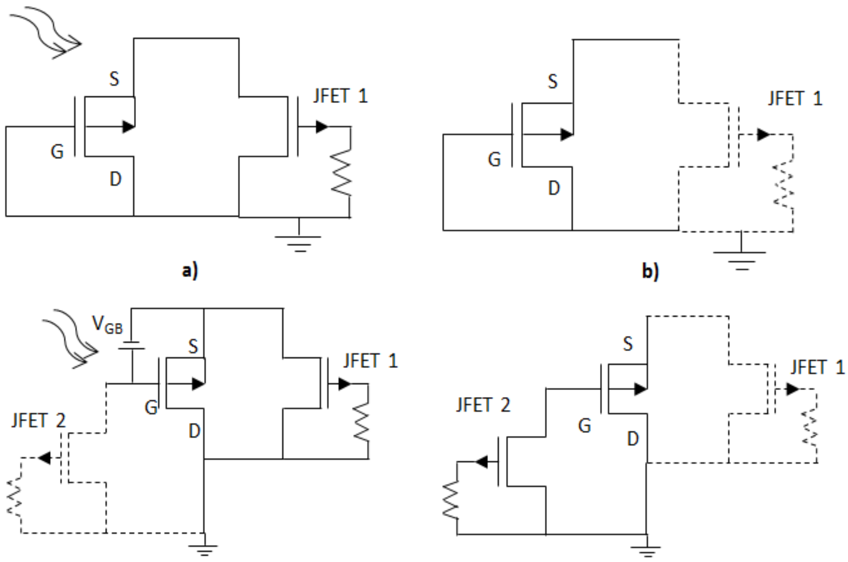


Fig. 1. a) Unbiased mode: during radiation period the JFET is on and the terminal are short-circuited all together. **b)** Unbiased mode: for readout process the JFET is cut off. **c)** Biased mode: during radiation period JFET2 is cut off with a bias source between the gate and source. **d)** Biased mode: for readout process JFET2 is on and JFET1 is off.

The different configurations of polarization depend on the model of MOSFET. For the 3N163 and the ZVP3306, V_{GS} values were 0, 5 and 10 V. However, the CD4007 model could only be studied biased to 0 and 0.6 V, because there is a protection diode between the source and the gate of the MOSFET, which turns on with a higher voltage than 0.6 V is applied.

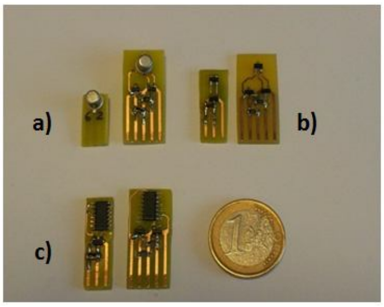
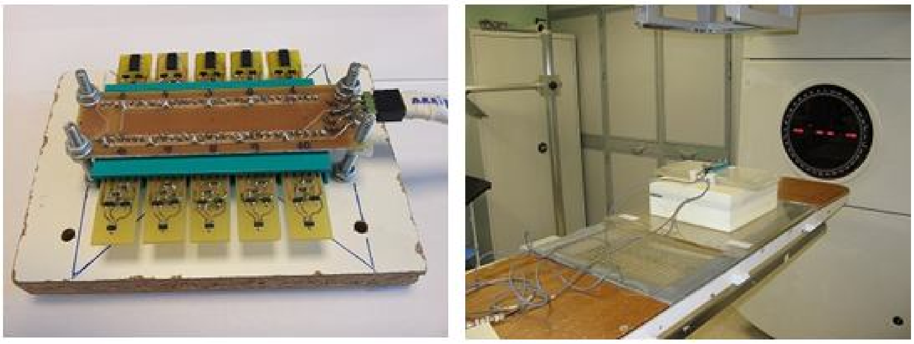


Fig. 2. Different sensors modules: **a)** 3N163 **b)** ZVP3306 **c)** CD4007

During the radiation period, for the biased mode (Figure 1, c), it was necessary additional circuits to supply the V_{GS} in the different values of 5 and 10V; and -21 V for opening the JFET 2.



a) b)

Fig. 3. a) PCB for biased mode. **b)** Experiment at hospital, inside the bunker of radiotherapy.

3 Results

The sensitivity is defined as the increment of V_T per dose unit (Gy), and was measured in unbiased and biased mode for each radiation sessions. For all models, the sensitivity was improved with the biased mode respect to the unbiased mode.

3.1 Photons

3N163 and ZVP3306 have been tested for gamma radiation with different configurations of polarizations. In a previous work [7], we had evaluated the response to gamma radiation in the unbiased mode of the 3N163 MOSFET. Now it was checked the enhancement of the sensitivity in the biased mode, comparing with another commercial MOSFET, the ZVP3306.

Table 1. Sensitivity (mV/Gy) for gamma radiation (6MV).

ZVP3306			**3N163**		
Bias (V)	**Sensitivity**	**SD**	**Bias (V)**	**Sensitivity**	**SD**
0	4.1	0.4	**0**	20.7	0.7
5	9.9	1.3	**5**	50.7	5.6
10	10.9	0.8	**10**	62.5	2.5

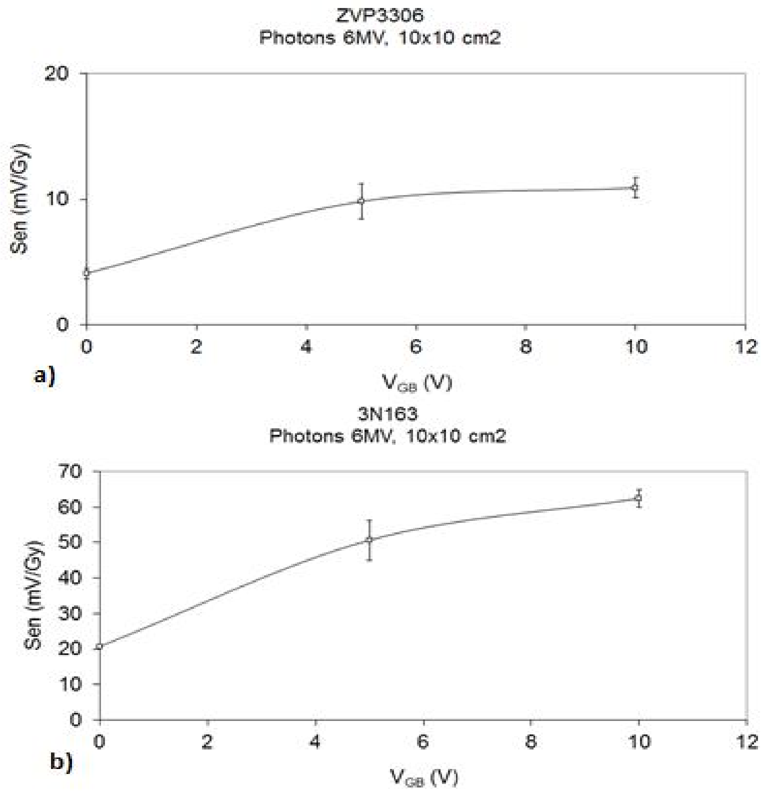


Fig. 4. a) Sensitivity of ZVP3306 for gamma radiation. **b)** Sensitivity of 3N163 for gamma radiation.

3.2 Electrons

For the radiation with electrons beams, the models CD4007 and ZVP3306 have been tested. The 3N163 MOSFET was not a good candidate for this radiation because the metallic encapsulate is incompatible with the electrons radiation.

Table 2. Sensitivity (mV/Gy) for electron beams (6 MV).

ZVP3306			CD4007		
Bias (V)	**Sensitivity**	**SD**	**Bias (V)**	**Sensitivity**	**SD**
0	3.8	0.2	**0**	4.7	0.1
5	7.3	0.4	**0.6**	8.02	0.1
10	9.1	1.2			

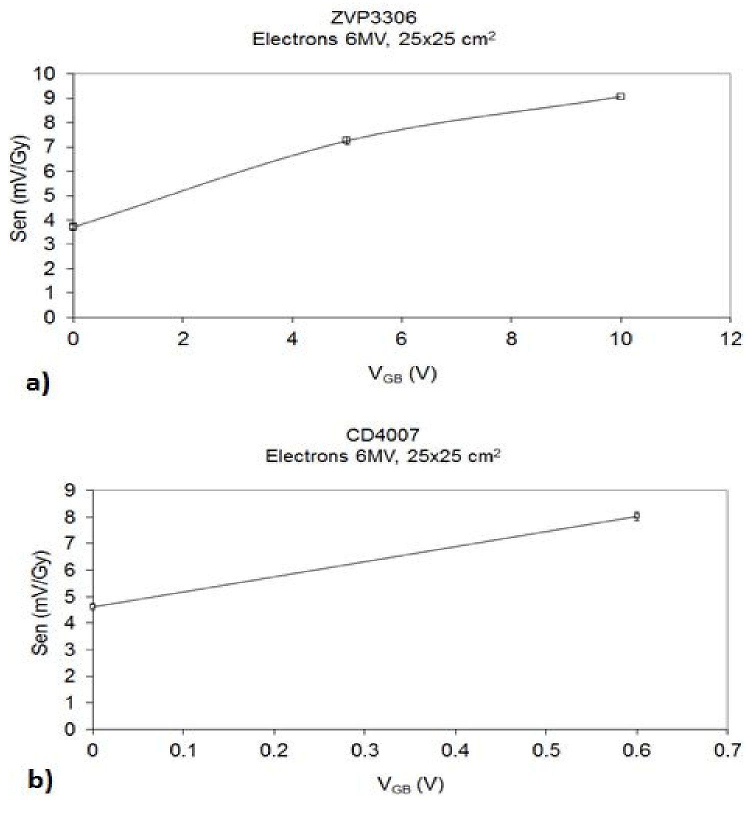


Fig. 5. a) Sensitivity of ZVP3306 for electron radiation. **b)** Sensitivity of CD4007 for electron radiation.

4 Conclusion

For each model of transistors, the sensitivity found in biased mode is higher than the sensitivity in unbiased mode, as it was expected.
For gamma radiation, with the MOSFETs 3N163 the improvement is almost lineal. Although it starts to saturate close to 7V, the values of the sensitivity are higher than the ZVP3306 model. In case of the electrons beams, it must be emphasized that the sensitivity increment of CD4007 MOSFETs with a low bias source is higher than other models. Only with 0.6V the sensitivity can be almost double. With the ZVP3306 model the increment is completely lineal.

The sensitivity of the model ZVP3306 presents a low dispersion for photons beams; however his averaged value is much lower than the sensitivity of 3N163. Thus, it was selected the 3N163 for photons dose measurements. In case of electrons beams, the ZVP3306 sensitivity biased at 10V is lightly higher than the sensitivity of CD4007 biased at maximum voltage (0.6V), and the dispersion found it is greater for ZVP3306. Therefore it was chosen the CD4007 as candidate as dosimeter for electron beams. With the correct electronic amplification and filtering and using the techniques describe in [6], these transistors in biased mode can be used in vivo dosimetry for clinical control in radiotherapy, reducing noticeably the cost of the future system, extending control in radiotherapy treatments and increasing the safety of the patient.

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