Study of the Annular Ellipsoidal Layout Style for MOSFETs in X-rays Ionizing Radiation Environments

W. S. Cruz[1], S. P. Gimenez[2] and L. E. Seixas[3]
[1,2] Centro Universitário da FEI
[3] CTI Renato Archer
e-mail: williamcruz@fei.edu.br

1. Abstract

This article presents a comparative study of the X-ray ionizing radiation effects between the annular ellipsoidal and standard rectangular layout styles for Metal-Oxide-Semiconductor Field Effect Transistors (MOSFETs), regarding the same gate area and bias conditions. The devices were manufacturing by using 180 nm Bulk Complementary Metal-Oxide-Semiconductor (CMOS) manufacturing process of Taiwan Semiconductor (TSMC). The results show that the annular ellipsoidal MOSFET is capable to presenting smaller variations of off-state current (I_{off}), approximately 40 times compared to variations of I_{off} in the rectangular counterpart.

2. Introduction

Many research efforts are conducted and high investments are made in order to design ever smaller MOSFETs and with better analog and digital electrical characteristics [1]. There are many ways to try to achieve these goals, among them we have the use of new materials for the manufacture of semiconductor devices, new planar and three-dimensional structures of MOSFETs, new manufacturing processes and new layouts [1]. All of these approaches either need high investments or increase the die area of integrated circuits (ICs). Recently an innovative layout technique was proposed, which uses non-standard gate geometries for MOSFETs (hexagonal/Diamond, octagonal/Octo, Ellipsoidal, Wave, and Fish) [2]. This layout approach does not add any additional cost for the current CMOS ICs manufacturing processes. When we use these gate shapes to implement MOSFETs, new effects are incorporated in their structures: Longitudinal Corner Effect (LCE), Parallel Connection of Different MOSFETs with Different channel Lengths Effect (PAMDLE) and Deactivation of MOSFETs in the Bird's Beak Regions Effect (DEPAMBBRE) [3].

Several experimental studies about these innovative gate layout geometries for MOSFETs have been showing that they are able to boost the electrical performance of MOSFETs in relation to those observed when they are implemented with the rectangular layout style [3]. Another potential gate layout for MOSFETs is the Annular Ellipsoidal gate geometry for MOSFETs (Fig. 1).

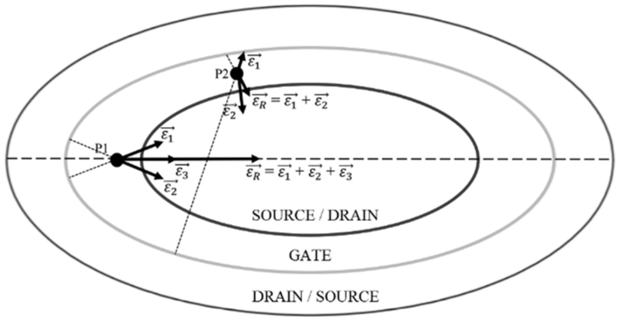

Fig.1. *The annular ellipsoidal MOSFET layout and the LCE.*

The Annular Ellipsoidal Gate MOSFET (AEGM) presents the LCE (represented in the Fig. 1) and does not present the PAMDLE and DEPAMBBRE effects (absence of the bird's beak regions, similar to the Circular Gate MOSFETs) [4]. Therefore, the motivation of this work is to perform a comparative study of the X-ray ionizing radiation effects between the AEGM and the Rectangular MOSFETs (RM) counterparts, regarding the same gate area (A_G) and bias conditions, focusing on the medical and aerospace CMOS ICs applications. The AEGM channel length is the same of the RM and its channel width is equal to its perimeter.

3. Annular Ellipsoidal Gate MOSFET

Based on Fig. 1, we can see that a portion of the AEGM gate region presents the LCE effect. Therefore, in this region the longitudinal electric field is higher than the one found in the RM counterpart. Consequently, the average velocity of the mobile carriers, which in turn the drain current (I_{DS}) along in the channel length of the AEGM is higher than the ones observed in the RM counterpart. Observe that in this structure the AEGM does not present the bird's beak regions, like the Circular Gate MOSFETs [4]. Therefore, it can boost the ionization radiation tolerance of MOSFETs. As more obtuse is the annular ellipse is, higher the LCE effect in this structure. The devices were manufactured with the 180 nm Bulk CMOS manufacturing process of the TSMC.

4. Irradiation procedure

The devices were exposed to an X-rays energy of 10 KeV by using the Shimadzu XRD-7000 diffractometer, which is capable of generating secondary electrons with a medium range of 500 nm [5]. Before being irradiated the MOSFETs, they were characterized by using the Keithley 4200-SCS system. During the process of X-rays ionizing radiation procedure, the MOSFETs were not biased. The chip was exposure regarding a Total Ionizing Dose (TID) of 3 Mrad and with a dose rate of 23.5 krad/min or 392 rad/s. After irradiation, the MOSFETs were again electrically characterized. All electrical characterizations were carried out at room temperature.

Table I presents the n-type MOSFETs (nMOSFETs) dimensions which were used to perfom this work.

Table I. *nMOSFETs Dimensions that were used to this study.*

	RM	AEGM
W [nm]	420	3860
L [nm]	180	260
W/L	2.3	14.8

Both nMOSFETs present the same threshold voltage (V_{TH}) of 0.47 V and they do not present short channel effect. In order to remove the effects of the MOSFET dimensions, the comparisons are done normalizing the electrical parameters in relation to their aspect ratios (AR)

$$AR = W/L. \tag{1}$$

5. Experimental results

Fig. 2 and Fig. 3 illustrate respectively the $I_{DS}/(W/L)$ and logarithm of the $I_{DS}/(W/L)$ curves as a function of gate bias (V_{GS}) for V_{DS} equal to 100 mV, measured before and after X-rays irradiation procedures, with a TID of 3 Mrad.

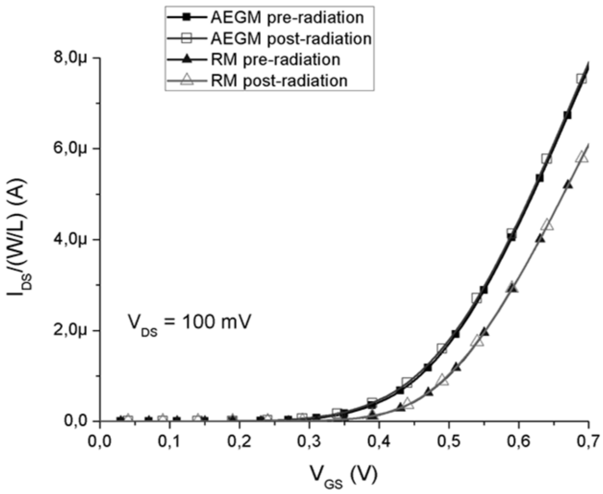

Fig.2. *$I_{DS}/(W/L)$ versus V_{GS}, for V_{DS} = 100 mV, of the AEGM and RM, regarding the pre-radiation and the X-rays post-radiatio (TID of 3 Mrad).*

Based on the Fig. 2, both the V_{TH} of nMOSFETs practically were not affected by the TID of 3 Mrad (X-rays), with a maximum variation of 0.12%, indicating that both devices are capable to be ionizing radiation tolerant for the TID considered of 3 Mrad. However, analysing Fig. 3, we can see that the RM was significantly affected by a TID of 3Mrad, while the AEGM practically does not varied due to the absence of the bird's beak regions. Therefore, the off-state drain current (I_{OFF}) of RM becomes about one order of magnitude higher than the one observed in the AEGM, after a TID of 3 Mrad (X-rays).

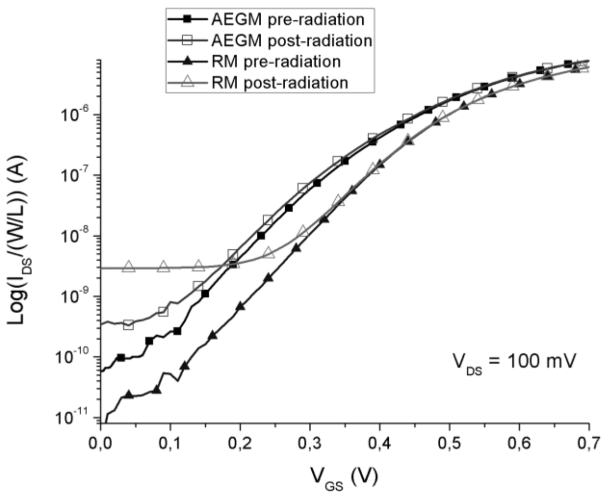

Fig.3. *$Log[I_{DS}/(W/L)]$ versus V_{GS}, for V_{DS} = 100 mV, of the AEGM and the RM, regarding the pre-radiation and the X-rays post-radiatio (TID of 3 Mrad).*

6. Conclusions

A comparative study of the ionizing radiation effects (TID) between the AEGM and RM was performed, regarding the same bias conditions. Both devices are tolerant considering a TID of 3 Mrad (X-rays). However, the I_{OFF} of the AEGM practically is not affected by the X-rays ionizing radiation of 3 Mrad due to absence of the bird's beak regions, in contrast of the RM, regarding the same bias conditions.

Acknowledgments

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References

[1] J. P. Colinge and C. A. Colinge, "Physics of Semiconductor Devices," Kluwer Academic Publishers, 2002.
[2] S. P. Gimenez, "Layout Techniques for MOSFETs," 1. Ed., Morgan & Claypool Publishers, 2016.
[3] S. P. Gimenez et. Al., "An innovative Ellipsoidal layout style to further boost the electrical performance of MOSFETs," IEEE Trans. Electron Device Letters, v. 36, no. 7, pp. 705-706, 2015.
[4] S. P. Gimenez et. Al., "Boosting the Radiation Hardness and Higher Reestablishing Pre-Rad Conditions by Using OCTO Layout Style for MOSFETs," SBMICRO, 2014, Aracaju.
[5] J. R. Schwank, M. R. Shaneyfelt and P. E. Dodd, "Radiation hardness Assurance testing of microelectronic devices and integrated circuits: radiation environments, physical mechanisms, and foundations for hardness assurance," Sandia Nat. Lab. Doc., Albuquerque, New Mexico, 2008.