STUDY OF MOSFETS IMPLEMENTED WITH ELLIPSOIDAL GATE LAYOUT OPERATING AS LIGHT SENSOR

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Abstract - The main objective of this work is to perform the experimental comparative study between the MOSFETs implemented with ellipsoidal and rectangular gate geometries operating as light sensors. The transistors were manufactured by using 180 nm Bulk CMOS technology. The main found of this experimental study attests that the responsivity normalized by the aspect ratio the Ellipsoidal MOSFET (E_M) is 53% higher in comparison to the one found in the standard rectangular MOSFET counterpart (C_M).

Keywords— Planar MOSFETs, Unconventional gate geometry (ellipsoidal), Photosensors, Electrical characterization.

I. INTRODUCTION

Nowadays we can observe that the research and development efforts in nanoelectronics are focused on the improvements of integrated circuits (ICs) through the use of new types of substrates, materials, and insulators aiming the reduction of parasitic capacitances and in the increase of the mobility of the mobile charge carriers of the channel [1]. However, these approaches involve high investments or increase the area of the die, which can often preclude the mass production of these ICs, since the goal is always trying to reduce the dimensions of devices [1**]**. Another way to achieve this, which is still little explored by the semiconductor and ICs industries, is the use of innovative gate layout styles for MOSFETs. This technique which simply changes the gate geometry of MOSFETs is very interesting because it presents zero cost [2]. Changes in gate layout styles of MOSFETs result in the presence of new effects, such as the Longitudinal Corner Effect (LCE) and the Parallel Connections of MOSFETs with Different Channel Length Effect, PAMDLE) [3]. The overlapping of these two effects acting on the MOSFET structure is able to boost its main merit figures (saturation drain current, transconductance, on-state series resistance, etc.). Studies by three-dimensional numerical simulations and by experimental results show that the MOSFET layouted with non-conventional gate geometry [hexagonal/Diamond (DM), octagonal (OM), ellipsoidal (EM), etc.] present a drain saturation current (I_{DSsat}) at least twice higher than that observed in the conventional rectangular one counterpart (CM), regarding that they present the same gate areas (A_G), channel widths (W) and bias conditions [4-5]. Therefore, the motivation of this work is to perform an experimental comparative study between the Ellipsoidal (EM) and conventional MOSFETs when they operate as light sensors (photo-sensors). In addition, the main merit figures of phototransistors, such as the responsivity, dark drain current and quantum efficiency are considered in this experimental study [6].

II. THE ELLIPSOIDAL MOSFET

An example of an Ellipsoidal MOSFET (layout and three-dimensional structure) is presented in Figure 1 [3].

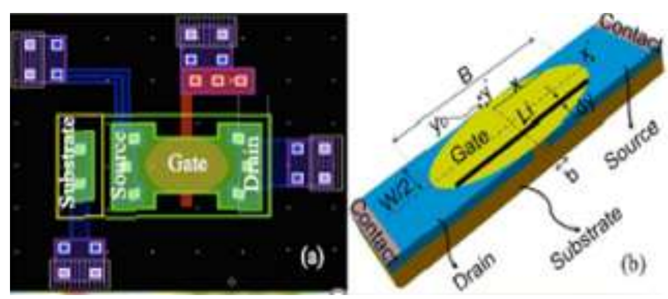

Figure 1: Exemple of an EM [Layout (a) and 3D structurenal EM (b)].

In Figure 1, B and b are the maximum and minimum channel lengths, 'W' is the channel width, 'dy' is the infinitesimal channel width.

III. PAMDLE EFFECT

The PAMDLE occurs in the EM because its channel length varies from b to B along of W. Therefore, the EM can be electrically represented by a parallel connection of infinitesimal standard rectangular MOSFETs (CM) with different channel lengths ($b \le L_i \le B$, which 'i' is an integer number) and the same channel width (dy=W/N, which N is an integer number tending to the infinite). Due to the drain current (I_{DS}) of a MOSFET is inversely proportional to the channel length, the PAMDLE forces the EM drain current (I_{DS}) to further flow by its edges because it presents the shortest channel lengths. Thanks the PAMDLE, the effective channel length of the EM (L_{eff_EM}) is always smaller than the one observed in the conventional rectangular MOSFETs and it is given by the equation (1) [3].

$$L_{eff\_EM} = B/[\sin^{-1}(1-b^2/B^2)^{1/2}] \qquad (1)$$

IV. LCE EFFECT

The change of the gate layout style of MOSFETs is able to generate the Longitudinal Corner Effect (LCE) which is responsible for the increase the resultant longitudinal electric field (LEF) between the drain and source regions of the MOSFET (Figure 2), that is given by the vector sum of the longitudinal LEF components. Therefore, the LCE forces the EM I_{DS} further flows in the center of the channel region than its edges. Therefore, considering an EM and an CM counterpart (same A_G, W and bias conditions), the resultant LEF of EM is always higher than the one observed of the CM counterpart [3].

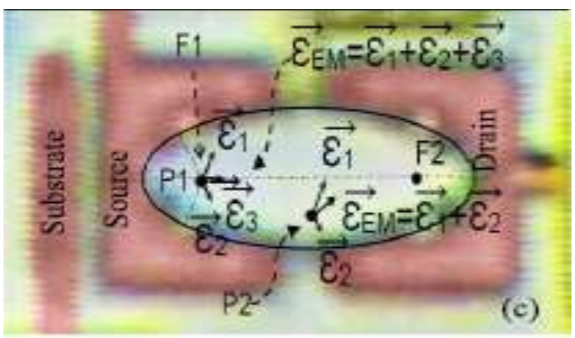

Figure 2: Photography of a EM manufactured indicating the LEF components and resultant LEF in two different point (P1 and P2) [3].

V. RESULTS

The experimental results were obtained by using the electrical characterization room of the Microelectronics laboratories of FEI University Center. The Keithley semiconductor devices electrical characterization system was used to perform the electrical characterization of the devices. For comparative purposes, the electric measurements of the devices were made with and without the presence of a light source. The devices were manufactured with 180 nm Conventional (Bulk) Complementary Metal-Oxide-Semiconductor (CMOS) of Integrated Circuits (ICs) of TSMC (implemented via mini@sic program of IMEC).

Table I presents the main dimensional characteristics of MOSFETs used to perform this work.

TABLE I. TRANSISTORS USED FOR CHARACTERIZATION

MOSFET TYPE	A_G (μm^2)	$B_{MÍN}$ (μm)	$B_{MÁX}$ (μm)	W (μm)	L_{eff} (μm)
CM	0.528	-	-	1.2	0.44
EM	0.512	0.18	0.76	0.82	0.40

A. Transconductance (gm)

The transconductance (gm) is given by Equation (1) [7].

$$gm = \frac{\partial I_{DS}}{\partial V_{GS}} \quad (S) \qquad (1)$$

In order to verify the better performance of the EM in relation to the CM counterpart, Figure 3 and 4 illustrate the transconductances as a function of the gate bias (V_{GS}), regarding the drain bias (VDS) of 0.5V, of devices with and without the presence of the light source (100 W lamp with put to a distance of the samples of 30 cm).

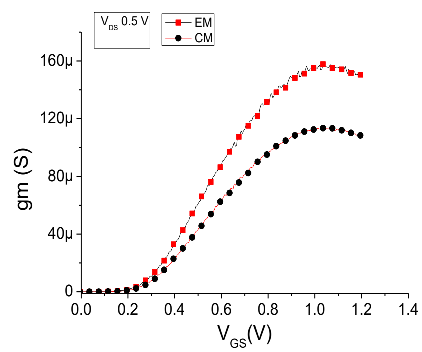

Figure 3: gm for (V_{DS} = 0.5V) in dark

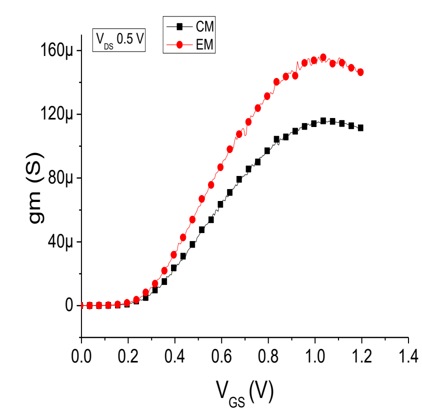

Figure 4: gm for (V_{DS} = 0.5 V) in ambient light

Analyzing Figures 3 and 4 and considering the practically the same gate area (A_G), we can observe that the EM presents a higher maximum transconductance (157 µS without the presence of light and 155.8 µS with the presence of light) in relation to the one of the CM (113 μS without the presence of light and 115.8 μS with the presence of light). This can be justified due to the LCE and PAMDLE effects.

B. Responsivity normalized for (W/L)

The responsivity [R/(W/L)] can be obtained by the ratio between the I_{DS} and incident light power in Watts in the photodetector [7-8]. Figure 5 illustrates the R/(W/L) as a function of gate bias (V_{GS}) for drain current (V_{DS}) of 0.5V, regarding a 100 W lamp put to a distance of the samples of 30 cm.

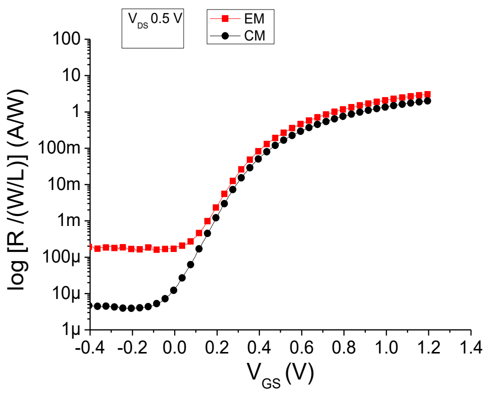

Figure 5: R/(W/L) of the EM and CM counterpart for V_{DS}= 0.5 V

Analyzing Figure 5, we can observe that the EM R/(W/L) is higher than the one found in the CM counterpart (higher one order of magnitude in the leakage region and 53% higher in saturation and triode regions).

VI. CONCLUSION

This work presents the experimental results obtained of a comparative study between the Ellipsoidal MOSFET and the rectangular conventional MOSFET taking into account the influence of the light energy. Based in this experimental study, we have observed that the EM is able to provide a better maximum transconductance (38%) and responsivity normalized as a function of the aspect ratio (53%) in relation to the one observed in the C_M counterpart. Therefore, the ellipsoidal layout style for MOSFETs is an alternative approach for boost the electrical performance of the light sensors.

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