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Yijun Zheng
Professor & Doctoral Supervisor, China Electronics Technology Group Corporation, the 58th Institute

Professor Weimin Shi
Department of Electronic Information Materials, Shanghai University

Mingshan Wang
Associate Researcher
China Electronics Technology Group Corporation, the 58th Institute

Hongyu Liu
Engineer
China Chemical Defense Research Institute

Chunzhi Zhou
Associate Researcher
China Chemical Defense Research Institute

Correspondence
Yijun Zheng
China Electronics Technology Group Corporation, the 58th Institute
Add: 5 Huihe Rd.,Wuxi jiangsu, China 214035,
Email: yijunzhengp@163.com

N-RADFET will able to replace P-RADFET

Yijun Zheng, Weimin Shi, Mingshan Wang, Hongyu Liu and Chunzhi Zhou

Abstract
This paper proposes the concept of quasi sensitivity and ultimate sensitivity, thereby reveals the reason for exclusive R&D of P-channel Radiation Field Effect Transistor (P-RADFET). The N-RADFET that was generally negated could replace P-RADFET to become RADFET mainstream. Under identical conditions, N-RADFET's ultimate sensitivity exceeds that of P-RADFET by 52.8%. The comparison is calculated based on the basic constant from published P-RADFET data. Therefore, this result does not need to do any experiments to verify.

Keywords: Radiation sensitive dosimeter, Radiation p-MOSFET sensitive dosimeter, Radiation detector.

1. Introduction

P-RADFET as an important type of sensors that have been widely used in nuclear radiation detection. In 2000 B. O. Connell developed 15 Stack-P-RADFET with sensitivity of 8.5 mV/mGy and output terminal voltage (V_O) of up to 10 V [1], which was the highest level for a P-RADFET detector at that time. Not only now, but also in the future for P-RADFET simultaneously achieve high sensitivity (dozens μV/mGy and several μV/mGy) and low working voltage (below 6v power supply voltage) is almost impossible. This is because the gate dielectric thickness in determining situations, increase P-RADFET's sensitivity is to increase the number of stacks in series, and the threshold voltage in determining situations, increase P-RADFET's sensitivity is to enhance increment (ΔV_{TP}) of each stack-P-RADFET induced by radiation is accumulated to the V_O, *i.e.,* increase the V_O. We want to further increase the sensitivity and reduce V_O are restricted by stacks number and V_O. Therefore, the resulting device was produced by a compromise scheme. On the contrary, due to the threshold voltage increment ΔV_{TN} of each stack-N-RADFET induced by radiation is offsetting the V_O, *i.e.,* reduce the V_O, along with higher electron mobility in N-RADFET, there is large potential in further increasing sensitivity and reducing V_O. However, the experiment of MGT (midgap technique) of P. J. McWhorter and Winokur using very thin gate dielectric (45nm) [2], according to the theory, the N-RADFET's ΔV_{TN} is equal to the difference between of the ΔV_{Not} and the ΔV_{Nit}, in other words the ΔV_{Nit} and the ΔV_{Not} contribution to ΔV_{th} are cancelled each other out, *i.e.,* $\Delta V_{TN} = \Delta V_{Not} - \Delta V_{Nit.}$ (such as Figure 1 show); Whereas the P-RADFET's ΔV_{TP} are equal to the sum of the ΔV_{Nit} and the ΔV_{Not} *i.e.,* $\Delta V_{TP} = \Delta V_{Not} + \Delta V_{Nit}$, this is very bad for the N-RADFET 's ΔV_{TN}. Figure 1 shows that the N-RADFET in four different radiation doses the average contribution of the ΔN_{it} (interface traps density increment induced by radiation) to the ΔV_{TN} is 41%, while the average contribution of the ΔN_{ot} (trapped-oxide charge density increment induced by radiation) to the ΔV_{TN} is 59%. The ΔV_{TP} is normalized 100% (59%＋41%), the ΔV_{TN} is only 18% (59% - 41%) of the P-RADFET. Note that the thinner of gate dielectric, the lower of the $\Delta V_{TN}/\Delta V_{TP}$ ratio. The results highlight the N-RADFET's ΔV_{TN} inferior, thereby likely to lead readers to believe that N-RADFET is far from as fine as P-RADFET. As the gate dielectric thickness increases, the $\Delta V_{TN}/\Delta V_{TP}$ ratio also increased significantly, and as well the correlative data [3] had indirectly shows that the ΔV_{TN} is close to ΔV_{TP}. In this case, the ultimate sensitivity of the N-RADFE is much higher than that of the P-RADFET, and the V_O is much lower than that of the P-RADFET. However, this fact didn't attract the researchers enough attention. Besides, it is noteworthy that no paper has reported that NMOS was not appropriate for the application in RADFET until now.

On the contrary, that the effect of the oxide-trapped charge on the mobility in n-channel devices are less pronounced than that in p-channel devices [3]. In order to comprehend high electron mobility in N-RADFET important contribution to the ultimate sensitivity, the V_O and the stability. Here must introduce the concept of quasi-sensitivity and ultimate-sensitivity (this article first propos).

2. Theoretical Analysis

2.1 In the case of thick gate dielectric the ΔV_{TN} close to the ΔV_{TP}

quasi sensitivity is determined by vertical structure parameters, such as the gate thickness and SiO_2/Si interface state; ultimate-sensitivity on the basis of quasi-sensitivity, is determined by the horizontal parameters, such as the channel (W/L), the channel carrier mobility and the readout circuit structure, W and L are the width and length of an RADFET. Based on the published data of ΔN_{ot} and ΔN_{it} [3, 5]. The ratio of the

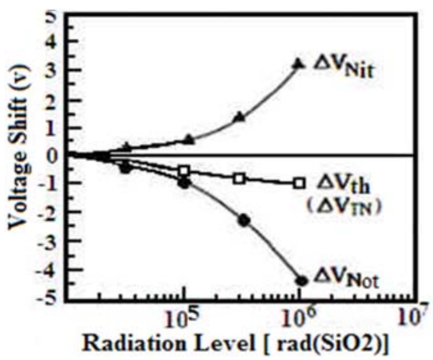

Fig 1: The ΔV_{th} and the contribution to that shift due to interface traps (ΔN_{it}) and trapped-oxide charge (ΔN_{ot}).

$\Delta N_{ot}/\Delta N_{it}$ increase along with gate dielectric thickness, It can be seen the ratio of $\Delta V_{TN}/\Delta V_{TP}$ increased from 18% (the paper of P. J. McWhorter *at al.,* gate dielectric thickness of 45 nm) to 48.32% (the paper of A. Jaksicet *at al.,* gate dielectric thickness of 400nm), and to 88.41% (the paper of G. Ristic *et al.,* gate dielectric thickness of 1.23 μm). The results show that thickening gate in N-RADFET caused the value of the ΔV_{TN} to become close to that of the ΔV_{TP}. But this is just the RADFET's quasi sensitivity.

2.2 N-RADFET obtaining high sensitivity, but also can reduce the V_O

Because the P-MOSFET and N-MOSFET different conduction types, the readout-circuit terminal voltage of the radiation signal in Stack-N-RADFET and Stack-P-RADFET was different. The ΔV_{TP} of the P-RADFET produced by irradiation is added to the output terminal to raise the V_O (higher voltage). On the contrary, the ΔV_{TN} of the N-RADFET offsets the output terminal to decrease the V_O (positive voltage decrease). Assuming that each stack-N-RADFET produces V_I after radiation, the V_O of the n stack-N-RADFET is $2nV_I$ lower than that of the same stack-P-RADFET and under same radiation signal. The reduction of the V_O was same with the enhancement of the sensitivity [1]. This is very important.

2.3 Ultimate-sensitivity comparison of N-RADFET and P-RADFET

There are the following expression in the article [4]

$$I_{sd} = -(W/L)\,\mu_p C_{OX} (V_O+V_T)^2/2\,(1+\delta). \quad (1)$$

I_{sd} is constant current, in which W/L, μp, C_{OX}, V_O, V_T, and δ are P-RADFET channel size, hole mobility (or N-RADFET channel size, electron mobility), unit area capacitance, output voltage, threshold voltage and the substrate bias factors respectively. In equation 1 can also be expressed as

$$V_O = -V_T - [2I_{sd}(1+\delta)/\mu_P C_{OX}(W/L)]^{1/2},$$

It was re-arranged by B. O. Connell, resulting in a new equation,

$$V_O = -V_T - [const/(W/L)]^{1/2}. \quad (2)$$

The specific "const" is extracted from the Figure 2 curves [1] and shared by the P-RADFET and the N-RADFET. The ultimate sensitivity of N-RADFE and P-RADFET were compared based on identical size, gate thickness and the factor δ. The plot of the variation in V_O versus the variation in W/L is shown in Figure 2 using the curve data, with an arbitrary number such as 100 from the horizontal axis, we can find the corresponding value of the vertical axis $dV_0/d(W/L)$ of -0.004. Then the equation 2 have been operated, *i.e.,* as below expression,

$$d V_O / d (W/L) = 1/2\,(const)^{1/2}(W/L)^{-3/2} = -0.004 \quad (3)$$

and $const^{1/2}$ of 8.0 (taking the absolute value) were obtained, according to the curve at the gate thickness 400nm. Thus, it is converted into the gate thickness 1.23μm, i.e., $const^{1/2}$ of 8.0 is converted into $const^{1/2}$ of 14.0, then

$$[2I_{sd}(1+\delta)/C_{OX}]^{1/2} = 14.0\ \mu_P^{1/2}.$$

Therefore, the simple expression of the V_O of the P-channel and N-channel RADFET before and after radiation is given below.

$$V_{OPB} = -V_T - 14\,[1/(W/L)]^{1/2}. \quad (4)$$
$$V_{OPA} = -V_T - \Delta V_{TP} - 14\,[1/(W/L)]^{1/2}. \quad (5)$$
$$V_{ONB} = V_T + 14\,[\mu_P/(\mu_n W/L)]^{1/2}. \quad (6)$$
$$V_{ONA} = V_T - \Delta V_{TN} + 14\,[\mu_P/(\mu_n W/L)]^{½} \quad (7)$$

Equations 4, 5, 6 and 7 gave the expressions of the V_O of the un-irradiated P-RADFET, the V_O of the P-RADFET after irradiation, the V_O of the un-irradiated N-RADFET, and the V_O of N-RADFET after irradiation, respectively. When the gate thickness (1.23 μm), the W/L=3060/13 (approximately 235), V_T (0.1V), ΔV_{TP} (0.1V), and ΔV_{TN} (0.088V), the values of V_{OPA} and the V_{ONA} were calculated to be -1.1133V and 0.5259V, respectively. According to the $(-V_{OPA}-V_{ONA})$ / $-V_{OPA}$ relation the value of relative decline between the V_{ONA} and the V_{OPA} was 52.8%. The reduction of the V_O was the same with the enhancement of the sensitivity, Figure 3 shows the ultimate sensitivity relative enhancing percentage

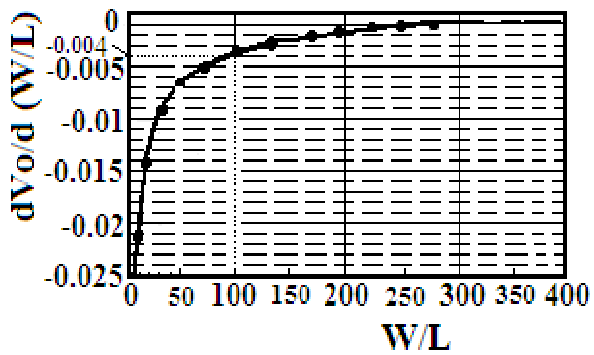

Fig 2: The variation of the reader circuit output voltage V_O with the W/L aspect ratio for a single device.

$((-V_{OPA}-V_{ONA}) / (-V_{OPA}))\times 100\%$ versus ΔV_T with different threshold voltage V_T. Thus, there is no need to make any experiment. A direct comparison of pros and cons between the N-RADFET's and the P-RADFET's ultimate sensitivity is obtained.

2.4 N-RADFET Stability surpass P-RADFET

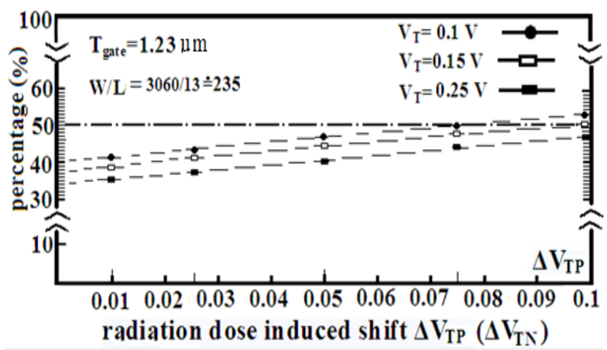

Fig 3: Ultimate sensitivity enhancing the percentage $((-V_{OPA}-V_{ONA}) /-V_{OPA}\times 100\%)$ versus ΔV_T

Reduce the degradation of RADFET after irradiation include increasing the thickness of the gate dielectric, increasing the positive bias voltage during irradiation [5] and avoiding the introduction of the instability interface-state, which is the same for N-RADFET and P-RADFET. In addition, the methods to effectively reduce the temperature drift were temperature compensation, common-mode rejection differential readout and readout current of the confirmed zero temperature coefficients (ZTC). The methods used in the P-RADFET were also suited to the N-RADFET. The N-RADFET can accommodate the more convenient technology of non-implanted thicker gate dielectrics [6] more convenient technology of non-implanted thicker gate to meet the reduce fading requirement of ultra-high sensitivity.

3. Conclusion

This article theoretical derived and calculated results based on the extracted basic constant from published P-RADFET data (curve) show the same chip size and equivalent gate thickness, and only changing the chip substrate (N type changing P type). N-RADFET's ultimate sensitivity exceeds that of the corresponding P-RADFET by 52.8%; The V_O of stack-N-RADFET is $2nV_I$ lower than that of the P-RADFET. The comparison is calculated based on the basic constant from published P-RADFET data. Therefore, this result does not need to do any experiments to verify. Admittedly have a direct experimental verification is more persuasive, But with respect to its academic value is almost the same, even in some sense is higher than the verified by experiment.

The N-RADFET that was generally negated not only could replace P-RADFET to become RADFET mainstream and also can be looking forward overall superior to the P-RADFET. In the foreseeable future the RADFET's history will be possible upside down that R&D the N-RADFET is exclusive, without the P-RADFET.

4. Acknowledgments

This article Figure 1 cited from the P. J. McWhorter article entitled "simple technique for separating the effects of interface traps and trapped-oxide charge in MOS transistors"; Figure 2 is cited from the B. O. Connell article entitled "optimized stacked RADFETs for micro-grey dose Measurement", and the data of A. Jaksicet's paper, the data of G. Ristic's paper. The authors express special thanks for their experimental data (curve), which is like the author personally made the experiment. It strongly supports the viewpoint in this paper, and makes our conclusion more convincing.

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