Applied Mechanics and Materials *Online: 2014-02-06*
ISSN: 1662-7482, Vols. 513-517, pp 2616-2619
doi:10.4028/www.scientific.net/AMM.513-517.2616

A Novel Resurf Stepped Oxide MOSFET with Slope Field Plate

Botao SUN [1, a], Lixin WANG [2,b], Yanfei ZHANG [3,c],
Limei SONG[4,d] Wei XIONG [5,e]

[1,2,3,4,5] Institute of Microelectronics of Chinese Academy of Sciences, Beijing, China

[a]sunbotao@ime.ac.cn, [b]wanglixin@ime.ac.cn, [c]zhangyanfei@ime.ac.cn,
[d]songlimei@ime.ac.cn, [e]xiongwei@ime.ac.cn

Keywords: RSO MOSFET, Slope Field Plate, Breakdown Voltage, Electric Field

Abstract. In this work, a new charge-coupling structure of RSO MOSFET with slope field plate is proposed. The design method is developed by theoretical analysis. In addition, a fabrication method using multi-plate to fit slope method is introduced. Then, a 250V structure was simulated to verify the theoretical analysis by TCAD. It is demonstrated that the structure overcomes the non-uniformity of electric field in drift region in traditional RSO MOSFET. The trade-off between the Ron and BV—"silicon limit" has been broken, for the Rdson=116 mΩ/mm^2 in this structure.

Introduction

Power MOSFETs are widely used in power switching and power amplification. There is always a demand for improving the devices with a lower on-resistance for a given breakdown voltage. In the conventional structure, the trade-off between the Ron and Breakdown Voltage (BV) is called "silicon limit", which is given by the following relation[1]:$Ron=5.93\times10^{-9}(BV)^{2.5}$.

A number of new device concepts have been proposed in order to break the "limit". One of the most noticeable is charge-coupling concept. In this concept, the electric field distribution in drift region has been altered from the triangular shape in the one dimension to a rectangular shape in the two dimensions. The most popular approach to meet charge-coupling is called "Super Junction", which is well suited for BV between 300~1200[2-4]. This approach is based on utilizing alternating P-type and N-type columns in the drift region. Recently another approach has emerged[5-6], which is called Resurf Stepped Oxide(RSO) MOSFET, based on an electrode embedded within oxide trenches in the drift region. It attracts wide attention due to compatibility with trench technology. However, the electric field in the drift region isn't uniform for the constant potential in the trench. When the desired blocking voltage is higher than 60V, this non-uniformity results in a low electric field through a large portion of the drain and source regions[2].This limits the application of this structure in a higher voltage area.

In this paper, a RSO MOSFET with slope field plate is proposed to overcome the non-uniformity of the electric field in drift region.

Device Theory and Fabrication Technology

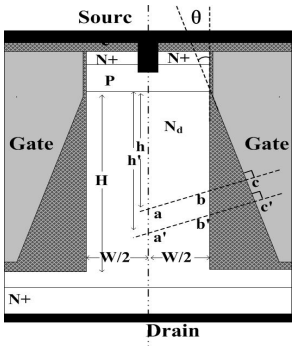

Fig.1 Schematic cross-section of Resurf Stepped Oxide MOSFET with Slope Field Plate

A schematic cross-section of the proposed device is shown in Fig.1. The oxide thickness between gate electrode and silicon drift region is gradual. This grade-oxide supports various voltages in different depth between gate electrode and silicon drift region. By suitable design, this structure can be fully charge-coupling. The design method is as follows.

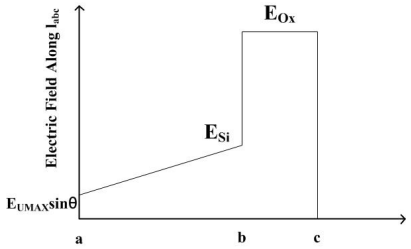

Fig.2 Electric field distribution along labc

It is supposed that the electric field in the middle of silicon drift region is constant, as the device breakdown. The constant value is equal to the critical electric field for the case of a uniform electric field E_{UMax}. The electric potential at point 'a' can be given by:

$$V_a = \frac{h}{H} BV = E_{UMAX} h \tag{1}$$

This electric potential also can be obtained by integral of electric field along l_{abc}, a straight line perpendicular to the slope field plate. The electric field distribution along l_{abc} is illustrated in Fig.2. $E_{UMax}\sin\theta$ is the vertical electric field in l_{abc}, where θ is the angle of slope field plate. The electric field varies linearly with distance in l_{ab} while the electric field in l_{bc} is constant. The "step" is the difference in dielectric constant between silicon and oxide. Another expression of V_a is given by:

$$V_a = -\frac{qN_d l_{ab}^2}{2\varepsilon_{Si}} - \frac{qN_d l_{ab} l_{bc}}{2\varepsilon_{Ox}} + l_{ab} E_{UMAX} \sin\theta \tag{2}$$

H and W are the length and width of the drift region respectively, N_d is the doping concentration in silicon drift region. The maximum value of N_d can be obtained by W and the maximum of E_{si}. Similar to above analysis, we can get the expression of V_a'. Then,

$$V_a - V_a' = E_{UMAX}\left(h - h'\right) = -\frac{qN_d W}{2\varepsilon_{Ox}}\left(h - h'\right)\tan\theta \tag{3}$$

$$\theta = \arctan\left(-\frac{2E_{UMAX}\varepsilon_{Ox}}{qN_d W}\right) = \arcsin\left(\frac{\varepsilon_{Ox} E_{UMAX}}{\varepsilon_{Si} E_{Si}}\right) \tag{4}$$

Accordingly, in order to have a uniform electric field in drift region, the angle of slope field plate (θ) should meet eq.4.

As it is difficult to fabricate specific angle trench in semiconductor technology, a structure of multi-plate is proposed to fit slope plate. Fig.3 shows a process flow of forming the multi-plate: (1) Form a deep trench filling with oxide in silicon; (2) Etch another trench in oxide. The trench width is equal to the bottom of the slope plate; (3) Fill this trench with an auxiliary material, as shown Fig3-a; (4) Wet etch the oxide D/n, where D is the oxide thickness of the field plate at bottom, as Fig3-b; (5) Dry etch the auxiliary material L/n, where L is the total length of the field plate; (6) Repeat (4) and (5) 'n' times, as Fig3-c. Finally, a slope plate like Fig3-d is obtained. The structure is closer to slope field plate when 'n' is larger.

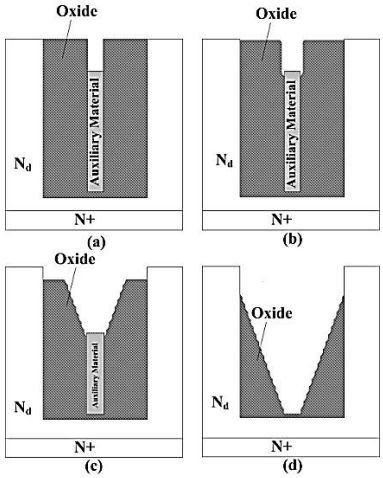

Fig.3 Process flow of forming the multi-plate

Simulation Analysis

This work addresses the study of the static performance of the RSO MOSFET with slope field plate using a 250V structure, by means of Sentaurus TCAD simulation. The main device parameters are as follows: H=10um, W=1um, $N_d=3.1\times10^{16}$. According to eq.4, sinθ is equal to 1/4. And by simulation, optimum sinθ is 1/5. The simulation result is in accordance with the analytical result. The electric field distribution along the vertical path in the middle of drift region is shown in Fig.4. The structure n=0 is a traditional RSO MOSFET. It is demonstrated that in the proposed structure n=10 the electric field nearly uniform. The peaks in x=0 and x=10um, are due to the mismatch in the top and bottom of the field plate. Fig.5 shows the breakdown voltage against the angle of slope field plate θ. It can be seen that increasing or decreasing θ will break the charge balance, and the BV will drop.

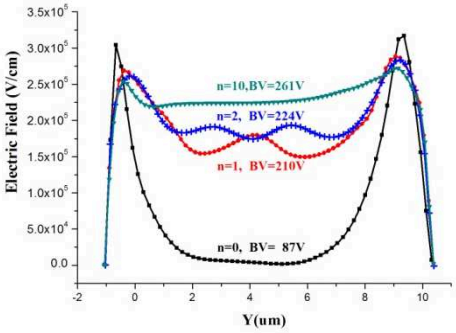

Fig.4 Electric field distribution in the middle of drift region

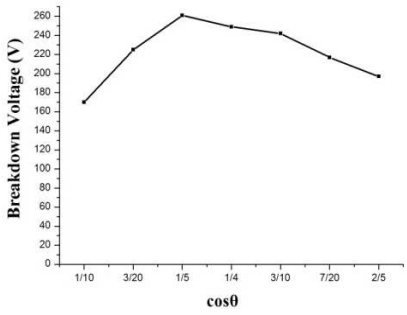

Fig.5 Breakdown voltage against θ

Fig.6-a shows the simulated electric potential contours for RSO MOSFET with slope field plate (sinθ ≈1/5, n=10). The potential contour in silicon and oxide is in accordance with previous section. In Fig.6-b, it can be observed that the impact ionization occurs at the middle of the drift region. This is because impact ionization is produced by vertical component of electric field.

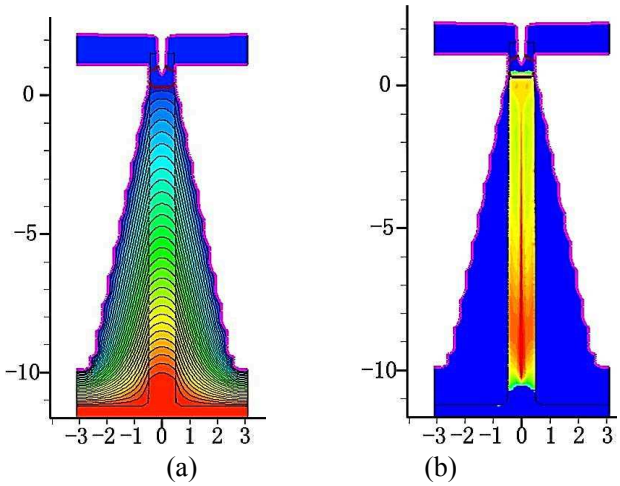

Fig.6 Electric potential contours (a) and impact ionization (b) in RSO MOSFET with slope field plate

The simulated R_{dson} is 116mΩ/mm^2 in this structure. And in "silicon limit", the R_{dson} is 586mΩ/mm^2, with a BV of 250V. So this structure breaks the "limit", in a higher BV than 60V.

Conclusions

This letter proposes a structure of Resurf Stepped Oxide MOSFET with slope field plate. A design method for fully charge-coupling structure is developed by theoretical analysis. And a fabrication method using multi-plate to fit slope method is proposed. A 250V structure was simulated to verify the theoretical analysis. The optimum angle of slope field plate and electric potential are in accordance with the analysis. And the electric field is nearly uniform in the drift region. This structure breaks the "silicon limit", for an R_{dson} of 116 mΩ/mm^2. This structure overcomes the defect of traditional RSO MOSFET. Therefore, it has the ability to apply in a higher BV.

References

[1] B.J Baliga: *Power Semiconductor Device* (PWS Publishing Company, Boston, 1996)
[2] B.J Baliga: *Advanced Power MOSFET* (Springer Science, New York, 2008)
[3] M Antonius, F Udrea, F Bauer, in: Optimization of SuperJunction Bipolar Transistor for Ultra-Fast Switching Application, International Symposium on Power Semiconductor Device and ICs, Jeju, Korea (2007).
[4] K. Takahashi, H. Kuribayashi, T. Kawashima, et al, in: 20mΩcm^2 660V Super Junction MOSFETs Fabricated by Deep Trench Etching and Epitaxial Growth, International Symposium on Power Semiconductor Device and ICs, Naples, Italy (2006).
[5] M. A. Gajda, et al, in: Industrialisation of Resurf Stepped Oxide Technology for Power Transistors, International Symposium on Power Semiconductor Device and ICs, Kitakyushu, Japan (2004).
[6] CF Tong, I. Cortes, P.A. Mawby, et al, in: Static and Dynamic Analysis of Split-Gate RESURF Stepped Oxide (RSO) MOSFETs for 35V Applications, Spanish Conference on Electron Devices, Santiago de Compostela, Spain(2009).