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High voltage (>1100 V) SOI LDMOS with an accumulated charges layer for double enhanced dielectric electric field

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Abstract: A high voltage silicon-on-insulator (SOI) LDMOS with an accumulated charges layer (ACL) for double enhanced dielectric electric field (DEDF) is proposed. The electrons and holes can be accumulated in the ACL with a back-gate bias in off-state. These charges can enhance the dielectric field in the buried oxide (BOX) layer under the source and drain for improving breakdown voltage (BV). Moreover, the ACL can also enhance the reduced surface field (RESURF) effect. Compared with the conventional SOI and Shield-Trench SOI, *BV* of the DEDF SOI can achieve 1163 V at 1 μm BOX and 550 V back-gate voltage.

Keywords: back-gate, breakdown voltage, high voltage, power semiconductor device, SOI

Classification: Electron devices, circuits, and systems

References

[1] S. Merchant, E. Arnold, H. Baumgart, S. Mukherjee, H. Pein, and R. Pinker, "Realization of high break-down voltage (>700 V) in thin SOI devices," *Proc. 3rd Conf. IEEE ISPSD*, Baltimore, USA, 146060, pp. 31–35, April 1991.

[2] X. Luo, B. Zhang, and Z. Li, "A new structure and its analytical model for the electric field and breakdown voltage of SOI high voltage device with variable-k dielectric buried layer," *Solid State Electron*, vol. 51, no. 3, pp. 493–499, 2007.

[3] X. Luo, B. Zhang, Z. Li, Y. Guo, X. Tang, and Y. Liu, "A novel 700-V SOI LDMOS with double-sided trench," *IEEE Electron Device Lett.*, vol. 28, no. 5, pp. 422–424, 2007.

[4] X. Luo, Z. Li, B. Zhang, Y. Guo, and X. Tang, "A novel structure and its breakdown mechanism of a SOI high voltage device with a shielding trench," *Chin. J. Semicond.*, vol. 26, no. 11, pp. 2154–2158, 2005.

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[5] H. Funaki, Y. Yamaguchi, K. Hirayama, and A. Nakagawa, "New 1200 V MOSFET structure on SOI with SIPOS shielding layer," *Proc. 10th Conf. IEEE ISPSD*, Kyoto, Japan, 702621, pp. 25–28, Aug. 1998.
[6] M. Qiao, B. Zhang, Z. Li, and J. Fang, "Analysis of back-gate effect on breakdown behaviour of over 600 V SOI LDMOS," *Electron. Lett.*, vol. 43, no. 22, pp. 1231–1232, 2007.
[7] Z. Wang, B. Zhang, Q. Fu, G. Xie, and Z. Li, "An L-Shaped Trench SOI-LDMOS With Vertical and Lateral Dielectric Field Enhancement," *IEEE Electron Device Lett.*, vol. 33, no. 5, pp. 703–705, 2012.

1 Introduction

Although silicon-on-insulator (SOI) has many advantages, low vertical breakdown voltage limits its application in high voltage power devices. Some structures are proposed to break through the limitation. A very effective method is enhanced dielectric layer field (ENDIF), such as ultrathin SOI, Variable-k SOI, Shield-Trench SOI (ST SOI) and Double-Sided Trench SOI and so on [1, 2, 3, 4]. In these devices, the electric field in the drain buried oxide (BOX) layer is enhanced greatly and breakdown voltage (BV) is mainly supported by the BOX under the drain. Another method is back-gate reduced bulk field (BG REBULF) [5]. BV is supported by the depletion layer and BOX under the drain and source at a proper positive back-gate bias. However, high positive back-gate voltage weakens the reduced surface field (RESURF) effect, resulting in increase of on-resistance and decrease of BV [5, 6].

To further improve BV, a SOI LDMOS with an accumulated charges layer (ACL) for double enhanced dielectric electric field (DEDF SOI) is proposed. The back-gate bias can result in inversion electrons accumulated under source for ENDIF. On the other hand, the potential difference of drain bias and back-gate bias can also result in accumulation of holes under drain for ENDIF. Moreover, the ACL also enhances the RESURF effect and improves lateral BV. So the proposed structures can achieve higher BV.

2 Mechanism and model

Conventionally, the dielectric filed (E_I) of the BOX can be expressed by equation $\varepsilon_I E_I = \varepsilon_{Si} E_{Si} + q\sigma_{in}$ [7]. E_{Si} is the electric field of silicon at Si/SiO_2 interface, ε_{Si} and ε_I are the permittivity of the silicon and dielectric buried layer. E_I can be enhanced by increasing the charge density (σ_{in}) at the Si/SiO_2 interface. Fig. 1 (a) shows the schematic cross-section view of the DEDF SOI. The ACL located between the SOI and BOX is introduced in this structure. The ACL consists of a p-type layer and oxide trenches as shown in Fig. 1 (a). When the back-gate and drain are with positive biases V_{BG} and V_{DS}, respectively, the holes in the drain-side trenches of the ACL are induced by V_{DS} as shown in Fig. 1 (b) and the electrons in the source-side trenches of the ACL are induced by the positive V_{BG} as shown in Fig. 1 (c). According to the electric displacement continuity, the dielectric field of the

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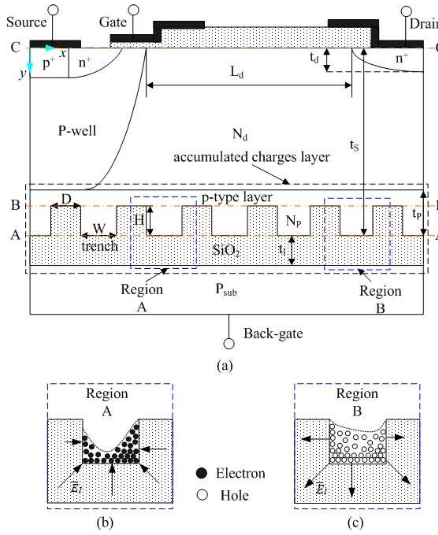

Fig. 1. (a) Schematic cross-section of the DEDF SOI, (b) Electrons accumulated in the trench, (c) Holes accumulated in the trench.

BOX under the source and drain ($E_{I,S}$ and $E_{I,D}$) [3, 4] can be written as

$$E_{I,S} = V_{BG}/t_I = q\sigma_{in}/\varepsilon_I \tag{1}$$

$$E_{I,D} \approx (V_{DS} - V_{BG} - 0.5E_S\,(t_S - t_d))/\,t_I = q\sigma_{in}/\varepsilon_I \tag{2}$$

Where E_S refers to the electric field at the p/n junction under the drain. In Eq. (2), a thin p-type layer in off-state is used to enhance the RESURF effect and improves the lateral BV. E_S can be calculated by N_d and N_p. As shown in Fig. 1, $E_{I,S}$ and $E_{I,D}$ can be effectively enhanced by the negative charges in Eq. (1) and positive charges in Eq. (2). The charge density depends on the ACL parameters, the drain voltage and positive back-gate voltage. Furthermore, the accumulated charges can modulate the electric field in the drift region. Therefore, the total BV can be generally obtained

$$BV \approx (E_{I,S} + E_{I,D})\,t_I + 0.5E_S\,(t_S - t_d) \tag{3}$$

In optimized BV, the maximum blocking voltage of the BOX under the source and drain is approximately same, *viz.* $E_{I,S} = E_{I,D}$. If the blocking voltage of the thin SOI, compared with the blocking voltage of the BOX, can be neglected in Eq. (3), the optimized $BV \approx 2q\sigma_{in}t_I/\varepsilon_I = 2V_{BG}$ can be obtained from Eq. (1), Eq. (2) and Eq. (3).

3 Results and discussion

The main electrical characteristics of the DEDF SOI are analyzed by MEDICI. In this paper, breakdown is defined as satisfying any one of two conditions. One condition is that the drain current achieves 10^{-7} A/μm, the other is that E_I achieves critical electric field ($E_{I,C}$ = 600 V/μm). Main parameters for verifying the devices in simulator MEDICI are that L_d, t_S, t_I and t_P are 100 μm, 4 μm, 1 μm and 1.5 μm, respectively.

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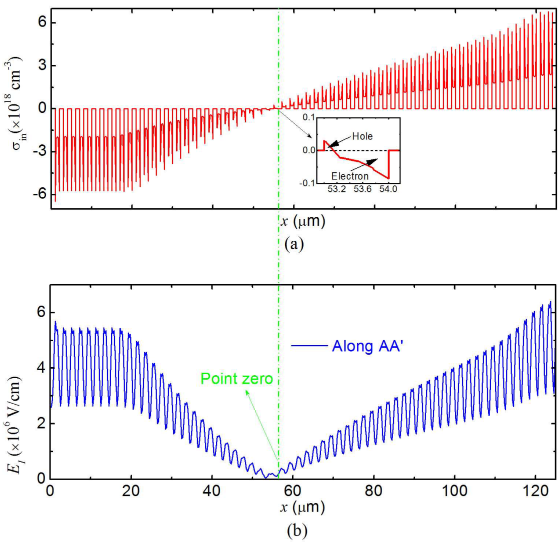

Fig. 2. (a) Charges in trenches along AA′ in Si side, (b) Electric field along AA′ in the SiO_2 side ($H = 1\,\mu$m, $D = 1\,\mu$m, $W = 1\,\mu$m, $N_p = 8 \times 10^{16}\,\text{cm}^{-3}$, $N_d = 4 \times 10^{15}\,\text{cm}^{-3}$, $V_{BG} = 500\,$V and $BV = 1113\,$V).

Fig. 2 (a) shows the charges distribution at the bottom of the trenches. The positive charge density, which is accumulated holes in the trenches, increases from $3.0 \times 10^{16}\,\text{cm}^{-3}$ to $6.8 \times 10^{18}\,\text{cm}^{-3}$ along +x axes, meanwhile, the negative charge density, which is inverse electrons in the trenches, increases from $2.2 \times 10^{16}\,\text{cm}^{-3}$ to $6.5 \times 10^{18}\,\text{cm}^{-3}$ along $-x$ axes. According to Eq. (1) and Eq. (2), the calculated $E_{I,S}$ and $E_{I,D}$ can be effectively enhanced to about $500\,\text{V}/\mu\text{m}$ and $600\,\text{V}/\mu\text{m}$ by these positive and negative charges, respectively. The inset in Fig. 2 (a) shows that the holes and electrons coexist in one trench for dividing the effect of V_{BG} in Eq. (1) and $V_{DS} - V_{BG}$ in Eq. (2). Fig. 2 (b) shows that $E_{I,S}$ and $E_{I,D}$ are enhanced by σ_{in}. The increment of E_I starting from zero point to both sides is undulating with the variation of σ_{in}. The negative charges accumulated by V_{BG} and positive charges by $V_{DS} - V_{BG}$ enhance $E_{I,S}$ and $E_{I,D}$ to about $600\,\text{V}/\mu\text{m}$.

Fig. 3 shows that the electric field distribution. The surface electric field along CC′ in the DEDF SOI, ST SOI and conventional SOI is shown in Fig. 3 (a). The electric field along BB′ can be modulated by the charges in the ACL. The RESURF effect is enhanced and premature breakdown is avoided. Hence, the surface electric field along CC′ is also modified by these charges to uniform distribution compared with the conventional SOI and ST SOI. Fig. 3 (b) shows the 3D electric field distribution. The electric field in the BOX is divided into two sections at point zero. One is caused by V_{BG} and the other is caused by $V_{D,S} - V_{BG}$. The maximum blocking voltage can be obtained by optimizing V_{BG} and other device parameters. Under this circumstances, $E_{I,S}$ in Eq. (1) is approximately equal to $E_{I,D}$ in Eq. (2). Fig. 3 (c) illustrates the equipotential contours at breakdown for the DEDF SOI. Because of the modulation of the electric field, its equipotential

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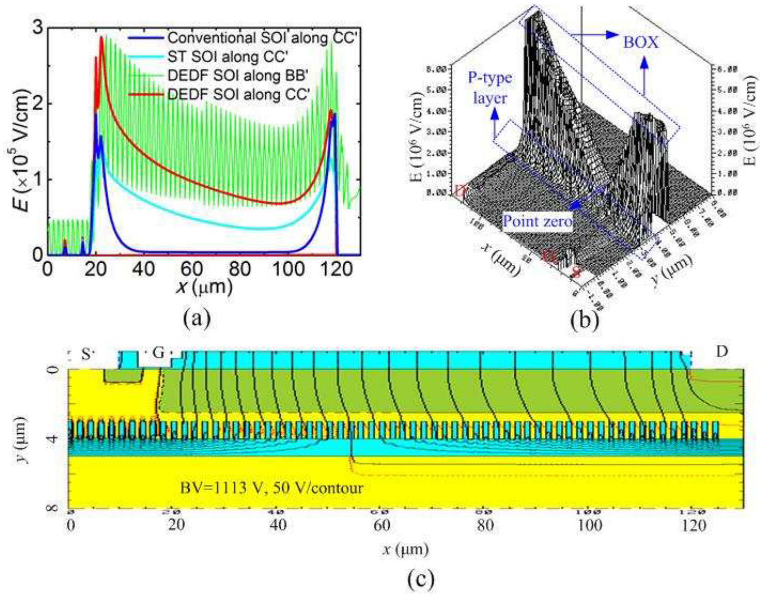

Fig. 3. (a) Electric field along BB′ and CC′ in the DEDF SOI, ST SOI, and conventional SOI, (b) 3D electric field distributions of the DEDF SOI, (c) Equipotential contour distribution of the DEDF SOI, The parameters and BVs for the DEDF SOI ($H = 1\,\mu$m, $D = 1\,\mu$m, $W = 1\,\mu$m, $N_p = 8 \times 10^{16}\,\text{cm}^{-3}$, $N_d = 4 \times 10^{15}\,\text{cm}^{-3}$, $V_{BG} = 500\,$V and $BV = 1113\,$V), ST SOI ($N_d = 1.0 \times 10^{15}\,\text{cm}^{-3}$, $V_{BG} = 0\,$V and $BV = 613\,$V), and conventional SOI ($N_d = 2.8 \times 10^{15}\,\text{cm}^{-3}$, $V_{BG} = 0\,$V and $BV = 188\,$V).

contours are uniform in the whole drift region.

Fig. 4 shows the dependences of optimized BVs of the DEDF SOI on the trench parameters (H, D and W). When H increases from $0.8\,\mu$m to $1.0\,\mu$m, σ_{in} is improved dramatically and E_I can be enhanced to $E_{I,C}$. Correspondently, BV increases to the maximum value rapidly, which is 1163 V, 1113 V and 1063 V at $V_{BG} = 550\,$V, 500 V and 450 V as shown in Fig. 4 (a). When H increases to $1.1\,\mu$m, BV is saturated due to achievement of $E_{I,C}$. Fig. 4 (b) shows that BV is dependent on the variation of D. When D is in the range of $0.6\,\mu$m to $1.0\,\mu$m, E_I can be enhanced to $E_{I,C}$ by σ_{in}. So BV keeps the maximum values at different V_{BG}. When D increases to $1.2\,\mu$m, σ_{in} is significantly reduced. Furthermore, the effective area of the p-type layer is reduced with increase of D, resulting in decrease of the RESURF effect. Hence, BV is decreased at different V_{BG}. At $V_{BG} = 550\,$V, BV is reduced to 921 V. Fig. 4 (c) shows that BV is dependent on the variation of W. The RESURF effect in the new structure is not weaken dramatically by the lower V_{BG}, therefore, the maximum BV (1063 V) is kept at $V_{BG} = 450\,$V with W increasing from $0.6\,\mu$m to $1.2\,\mu$m. At higher V_{BG}, BV is lower at $W = 0.6\,\mu$m. Large W means large p-type layer which can enhance the RESURF effect. So BV increases with W increasing and achieves the maxi-

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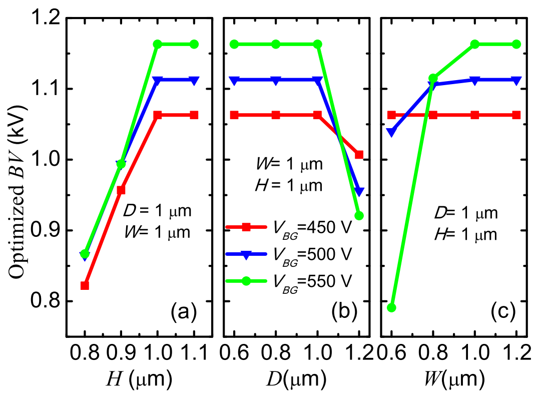

Fig. 4. The optimized BVs dependent on trench parameters (H, D and W) in (a), (b) and (c).

mum value (1113 V and 1163 V at $V_{BG} = 500$ V and 550 V) at $W = 1.1\,\mu$m. BV no longer increase at $W = 1.2\,\mu$m because E_I is limited to $E_{I,C}$.

4 Conclusion

The DEDF SOI with high performance is proposed and investigated. Due to the ACL introduced for double enhanced dielectric field, the BV has been remarkably improved and can achieve 1163 V at $V_{BG} = 550$ V, which is about 6 times as high as that of the conventional SOI.

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