第23卷第10期　　半 导 体 学 报　　Vol. 23, No. 10
2002年10月　　CHINESE JOURNAL OF SEMICONDUCTORS　　Oct., 2002

Improvement of Electrical Performance of SOI-LIGBT by Resistive Field Plate*

Yang Hongqiang, Han Lei and Chen Xingbi

(*Institute of Micro-Electronics and Solid-Electronics, University of Electronic Science and Technology, Chengdu* 610054, *China*)

Abstract: The electrical performance including breakdown voltage and turn-off speed of SOI-LIGBT is improved by incorporating a resistive field plate (RFP) and a p-MOSFET. The p-MOSFET is controlled by a signal detected from a point of the RFP. During the turning-off of the IGBT, the p-MOSFET is turned on, which provides a channel for the excessive carriers to flow out of the drift region and prevents the carriers from being injected into the drift region. At the same time, the electric field affected by the RFP makes the excessive carriers flow through a wider region, which almost eliminates the second phase of the turning-off of the SOI-LIGBT caused by the substrate bias. Faster turn-off speed is achieved by above two factors. During the on state of the IGBT, the p-MOSFET is off, which leads to an on-state performance like normal one. At least, the increase of the breakdown voltage for 25 % and the decrease of the turn-off time for 65 % can be achieved by this structure as can be verified by the numerical simulation results.

Key words: resistive field plate; dynamic controlled anode-short; turn-off time; breakdown voltage; forward voltage drop

EEACC: 1210; 2560

CLC number: TN386　　**Document code:** A　　**Article ID:** 0253-4177(2002)10-1014-05

1 Introduction

Power device is widely used in different fields. But the contradictive relationship among the on-state power dissipation, breakdown voltage, and switching speed restricts its use in most situations. For example, it is always a problem that the long time taken to turn off an IGBT can not be reduced without affecting the other characteristics significantly. Some solutions, for example, anode-short, minority-carrier-lifetime-control, etc, have been put forward to resolve the problem of IGBT. The technique of anode-short is the most effective one. It can reduce the turn-off time by preventing the injection of the carriers and providing a way for the excessive carriers to disappear more quickly. But there is still a drawback that the anode-short structure will decrease the efficiency of carrier injection during on-state, which causes the forward voltage drop much lower. Finding a new structure that can improve the whole performance of IGBT will be great valuable.

Different solutions for above problem are described based on the dynamic controlled anode-short. Neverthe-

---

* Projcet supported by National Natural Science Foundation of China (No. 69776041)

Yang Hongqiang　male, was born in 1974, PhD candidate. His research lies in the field of SOI, power device, and power ICs.

Han Lei　male, was born in 1968, PhD candidate. He is interested in power device and smart power IC.

Chen Xingbi　male, was born in 1931, academician of The Chinese Academy of Sciences. His current research includes power devices, smart power ICs and device physics.

Received 8 February 2002, revised manuscript received 26 April 2002

less, among these methods, some are unfit for sustaining high voltage[1], some need complicated driving circuits[2,3], and some can only be used in a special circuits[4]. Some new structures yielding better performance with the same driving circuits of a conventional IGBT are expected. That is the purpose of this paper.

2 Theoretical analysis

The most important parts of the new structure of IGBT proposed are the RFP and the p-MOSFET, whose source and drain are connected to the anode and buffer region of the IGBT, respectively. The p-MOSFET acts as a dynamic anode-short structure and is controlled by the signal detected from a point of the RFP, in other words, controlled by the anode voltage indirectly since the RFP is connected to the cathode and anode. A schematic diagram of the new structure of SOI-LIGBT is shown in Fig. 1, in which K, G and A are the electrodes of cathode, gate and anode of a conventional LIGBT. G1 is the gate used for dynamic controlled anode-short. R_L is the load resistor of IGBT. Compared to a normal IGBT, an additional p-MOSFET is in this structure. When the IGBT is in the onstate, the difference of the electrical potential between the anode and the cathode takes the minimum value, which causes minimum gate voltage of G1. Then the p-MOSFET will be off, and the anode-short structure will stop working. The on-state power dissipation of the IGBT maintains a very small value. During the course of turning-off, the potential difference between the anode and the cathode increases with the increase of anode voltage. When the anode voltage reaches a critical value, the p-MOSFET will be turned on, which prevents the injection of the carriers and makes the excessive carriers of the base region disappear more quickly. Then a faster turn-off speed is achieved.

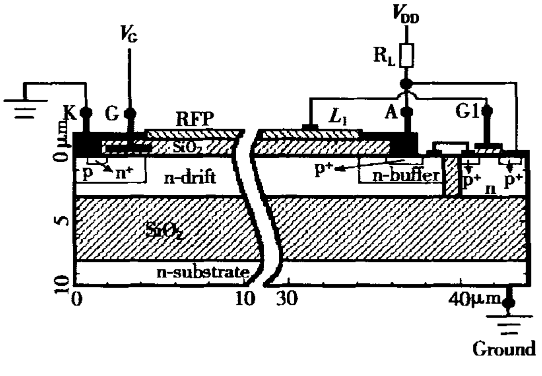

Fig. 1 Schematic diagram of the new structure IGBT (shadow region stands for oxide or RFP)

It is necessary to point out that there are three phases in the turning-off of a normal SOI-LIGBT, and the second phase caused by the substrate bias is an additional part compared to a normal IGBT[5]. In our new structure, the electric field affected by the RFP makes the excessive carriers flow through a wider region, which almost eliminates the second phase. Faster turn-off speed is achieved.

It is important to decide the point from which the gate voltage of G1 is detected, in other words, the ratio of the length of the RFP at the right of this point to that of the total, since either the on- or off-state of the p-MOSFET is decided by it. A too large value of the ratio leads to a higher voltage than the threshold voltage of the p-MOSFET all the time, which makes the p-MOSFET be always in its on-state. Then the anode-short structure always works, and the IGBT has a higher forward voltage drop. On the other hand, too small a value of the ratio can not turn on the p-MOSFET during the turning-off of the IGBT, which leads to a turn-off time just like the normal one. So, the compromise between the forward power dissipation and the turn-off time should be considered.

3 Simulation analysis

TMA/MEDICI[7] is used for simulation to verify the validation of the theoretical analysis in the part two. The new structure for simulation is shown in Fig. 1, which indicates the dimensional parameters. The other parameters are given in Table 1. Different values of L_1 are given to achieve the optimum result by considering the tradeoff of the turn-on performance and the turn-off speed. The normal IGBT is just the same as the new structure without the

RFP and the p-MOSFET, and the parameters are the optimum ones for the normal IGBT. Both of the new and the normal structure are simulated.

Table 1 Parameters for simulation

Parameters	Values	Unit
Concentration of n-substrate	10^{15}	cm^{-3}
Concentration of n-drift	10^{15}	cm^{-3}
Concentration of n-buffer	10^{17}	cm^{-3}
Concentration of n^+ and p^+	10^{20}	cm^{-3}
Concentration of channel region	10^{17}	cm^{-3}
Threshold voltage of p-MOSFET	6	V
Thickness of the gate oxide	0.1	μm
Distance from the detected point to the right of the RFP(L_1)	1.5, 2, 2.5	μm
Total length of the RFP	30	μm
R_L	2	MΩ/μm
V_{DD}	250	V
Gate voltage V_G	15	V
High injection lifetime	20	μs

The curves of the turn-on and turn-off corresponding to different values of L_1 by simulation are shown in Figs. 2 and 3. From the figures, the conclusion can be drawn that larger L_1 leads to poorer turn-on performance but faster turning-off. The case of $L_1 = 2$μm is taken as an example to give the explanation of the turn-on and turn-off mechanism.

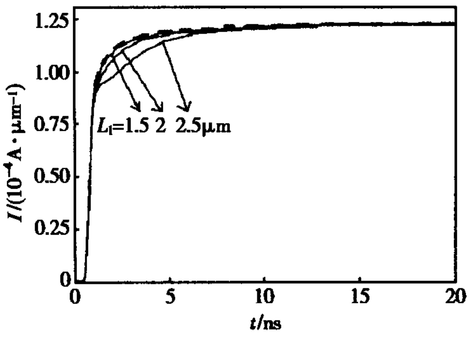

Fig. 2 Turn-on curves Solid line: new structure; Dash line: normal IGBT

The potential difference between the gate G1 and the anode A, the source of the p-MOSFET, versus time during the turning-on and turning-off is shown in Fig. 4(a) and

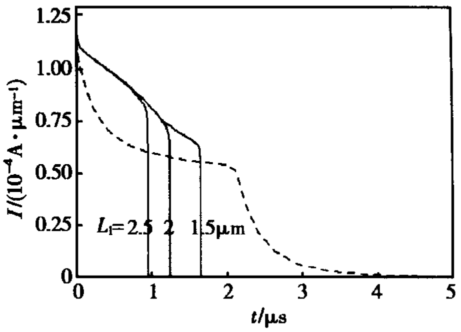

Fig. 3 Turn-off curves Solid line: new structure; Dash line: normal IGBT

(b). According to Fig. 4(a), the potential difference is larger than the threshold voltage of the p-MOSFET before the time of 7.5ns, which turns on the p-MOSFET, so the IGBT works in anode-short mode, and the anode current is smaller than that of a normal IGBT. After that, the voltage added on G1 decreases, the p-MOSFET is not in its on-state any more, which makes the anode current rise to the level as normal. The degradation of the turn-on performance can be neglected since the difference between the

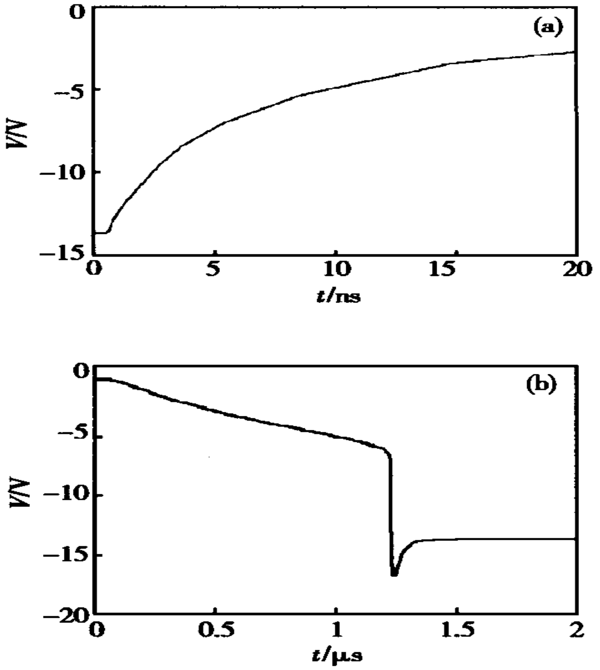

Fig. 4 (a) Potential difference between the gate G1 and the anode during the course of turning-on; (b) Potential difference between the gate G1 and the anode during the course of turning-off turning on of the new structure and that of the normal IGBT is very small (in Fig. 1, the curves of the normal case and that of $L_1 = 1.5\mu m$ almost overlap).

After the turning on, the IGBT reaches its on-state. According to the results of simulation, the values of the forward voltage drop for the new structure and the normal IGBT are the same, which are 1.43V, while the values of the anode current both equal to 1.2429A/μm. This is the precondition for comparing the turn-off course of the two structures of IGBT.

Figure 4(b) shows the potential difference between the gate G1 and the anode during the course of turning-off. During the period of 0 to 1.2μs, the voltage added on G1 is smaller than the threshold voltage of the p-MOSFET. The excessive carriers of the drift region disappear in the normal way. The new structure does not affect the turning-off. But after that, the gate voltage of G1 is higher than the threshold voltage, and goes on increasing with the time. The channel of the p-MOSFET is generated, which acts as an anode-short structure of the IGBT. So, from then on, the excessive carriers disappear faster, and the anode current will decrease to zero soon. There is no more a long tail in the turn-off curve, which makes the turn-off time of the device decrease significantly.

As it is well-known the introducing of an RFP can improve the breakdown voltage of the LIGBT. The breakdown voltage of 320V is achieved for the new structure while only 257V for the normal structure.

4 Discussion and conclusion

If there is no dielectric insulator between the IGBT and the p-MOSFET, in other words, the anode of the IGBT and the source of the p-MOSFET are corresponding to the same p^+-region, and the drain of the p-MOSFET lies in the n-buffer region, the parasitic transistor p^+ (anode) n (n-buffer) p^+ (the additional p^+-region) will work as a recombination center, which reduces the concentration of the excessive carriers of the n-buffer region, then leads to a higher forward voltage drop while it is in on-state. If the above drawback is accepted, the new structure can be used in bulk silicon device as well as in SOI device, and fewer additional requirements for the fabrication are needed.

The parameters for simulation are the optimum ones for the normal IGBT as described in part 3, and it is more impersonal to show the advantage by comparing the new structure with an optimized normal IGBT. A great improvement of the performance of the IGBT was achieved according to the results of simulation. Turn-off time decreases for about 65% and breakdown voltage increase for 25%, while on-state performance is almost the same as the normal.

In order to consider the performance of the new structure once the parameters are changed, two situations are simulated: (1) Decrease the impurity concentration of the drift region and the injection efficiency; (2) Increase both of them. When the values of the concentration of the drift region and the anode region are $2\times10^{14}cm^{-3}$ and $1\times10^{19}cm^{-3}$, the values of the breakdown voltage are 212V and 299V for the normal IGBT and new structure, respectively, increasing about 40%, and the values of the turn-off time are 0.45μs and 0.15μs, decreasing about 66%. When the values of the concentration of the drift region, the anode region and the buffer region are 5×10^{15}, 1×10^{20} and $1\times10^{16}cm^{-3}$, the values of the breakdown voltage are 70V and 430V, increasing about 500%, and the values of the turn-off time are 30μs and 1μs, decreasing about 96%. Obviously, the improvement of the performance is more significantly after varying the parameters, while the performance of the normal IGBT degrades much.

References

[1] Boisvert D M, Plummer J D. The complementary insulated-gate bipolar transistor (CIGBT) ——A new power switching device. IEEE Electron Device Lett, 1990, 11(9): 368

[2] Plikat R, Xu Shuming, Silber D. Comparison of different switched anode emitter short concepts for IGBTs. ISPSD, 1998: 257

[3] Lee B H, Kim S D, Byeon D S, et al. Dual-gate shorted-anode LIGBT

with p$^+$ injector eliminating the negative resistance regime. ISPSD, 1998:269

[4] Yang Hongqiang, Chen Xingbi. Realization of a high speed, low power dissipation low side device of the half bridge output section. Acta Electronica Sinica, 2001, 29(6): 814 (in Chinese) [杨洪强,陈星弼. 半桥式功率输出级中高速低功耗低侧管的实现. 电子学报, 2001, 29(6): 814]

[5] Garner D M, Udrea F, Lim H T, et al. An analytic model for turn off in the silicon-on-insulator LIGBT. Solid-State Electron, 1999, 43: 1855

[6] He Jin, Wang Xin, Chen Xingbi. Preparation of PT-IGBT with new structure based on SDB. Chinese Journal of Semiconductors, 2000, 21(9): 877 (in Chinese) [何进,王新,陈星弼. 基于 SDB 技术的新结构 PT 型 IGBT 器件研制. 半导体学报, 2000, 21(9): 877]

[7] MA/MEDICI User's Manual, Version 2.1.2 TMA, Inc., 1994

[8] Yang Hongqiang, Chen Xingbi. A high speed IGBT based on dynamic controlled anode-short. Chinese Journal of Semiconductors, 2002, 23: 347

[9] Wu Yu, Lu Xiuhong, Kang Baowei, et al. A novel low power loss IGBT (LPL-IGBT) and its simulation. Chinese Journal of Semiconductors, 2001, 22: 1565 (in Chinese) [吴郁,陆秀洪,亢宝位,等. 低功耗 IGBT(LPL-IGBT)及其仿真. 半导体学报, 2001, 22: 1565]

[10] Chen Xingbi. Power MOSFET and HVIC's. Nanjing: South-East University Press, 1990 (in Chinese) [陈星弼. 功率 MOSFET 和高压集成电路. 南京:东南大学出版, 1990]

利用电阻场板提高 SOI-LIGBT 的性能*

杨洪强　韩　磊　陈星弼

(电子科技大学微电子与固体电子学院, 成都　610054)

摘要: 通过在 SOI-LIGBT 中引入电阻场板和一个 p-MOSFET 结构, IGBT 的性能得以大幅提高. p-MOSFET 的栅信号由电阻场板分压得到. 在 IGBT 关断过程中, p-MOSFET 将被开启, 作为阳极短路结构起作用, 从而使漂移区的过剩载流子迅速消失, IGBT 快速关断. 而且由于电场受到电阻场板的影响, 使得过剩载流子能沿着一个更宽的通道流过漂移区, 几乎消去了普通 SOI-LIGBT 由于衬偏造成的关断的第二阶段. 这两个因素使得新结构的关断时间大大减少. 在 IGBT 的开启状态, 由于 p-MOSFET 不导通, 因此器件的开启特性几乎与普通器件一致. 模拟结果表明, 新结构至少能增加 25 %的耐压, 减少 65 %的关断时间.

关键词: 电阻场板; 动态控制阳极短路; 关断时间; 击穿电压; 正向导通压降

EEACC: 1210; 2560

中图分类号: TN386　　**文献标识码**: A　　**文章编号**: 0253-4177(2002)10-1014-05

---

* 国家自然科学基金资助项目(批准号: 69776041)

杨洪强　男, 27 岁, 博士研究生, 目前研究方向为 SOI、IGBT 及功率 IC.

韩　磊　男, 33 岁, 博士研究生, 目前研究方向为功率器件及功率 IC.

陈星弼　男, 70 岁, 中国科学院院士, 目前研究方向为器件物理、功率器件及功率 IC.

2002-02-08 收到, 2002-04-26 定稿