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Study of Off-State Breakdown Improvement and Hot-Carrier Reliability in LDMOS Device with Gradual Junction Structure

Chin-Rung Yan[1], Jone F Chen[1], Chung-Yi Lin[2], Hao-Tang Hsiu[2], Yu-Chieh Liao[2], Min-Ti Yang[2], Ying-Chia Lin[2], Huei-Haurng Chen[2]

[1] Institute of Microelectronics, Department of Electrical Engineering, National Cheng Kung University, Tainan, Taiwan
Phone: +886-3-579-5000 ext.8709 E-mail: darren0613@gmail.com
[2] Device Technology Group, Powerchip Technology Corp., Hsin-Chu, Taiwan

1. Introduction

Both off-state breakdown voltage (V_{BD}) and on-resistance (Ron) performances are the major considerations in designing LDMOS devices. However, these two parameters are usually trade-off with each other. In this work, a gradual junction structure is used to improve off-state V_{BD} without sacrificing device drivability. Experimental data of V_{BD} improvement and hot-carrier induced device degradation are presented and discussed. In addition, TCAD simulation results of electric field and impact ionization (I-I) rate are analyzed to explain the experimental data. Finally, electrical safe operating area (E-SOA) of devices is investigated. The device with gradual junction structure has wider E-SOA range.

2. Experiment

The dimensions of W/L and gate oxide thickness of the device used in this work are 10/0.9 um and 40 nm, respectively. Fig. 1(a) and (b) show the schematic process flows to fabricate LDMOS device with traditional and gradual junction structures, where the self-alignment implant of N- region experience uniform and gradual screen oxide thickness. The gradual screen oxide structure, which is formed by dual oxide (8nm and 40nm) process, leads to gradual junction profile in N- region of LDMOS device. After self-alignment implant of N- region, a n+ implant with a distance 0.75 um to the poly gate is defined.

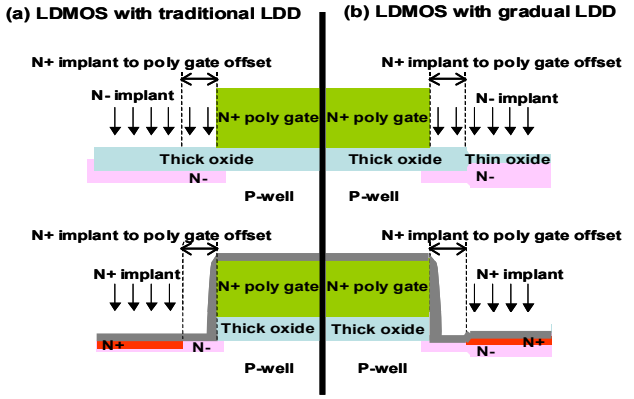

Fig. 1 (a) and (b), the schematic process flows to fabricate traditional and gradual junction structures are compared.

3. Experiment Results and Discussions

Fig. 2 shows the off-state breakdown characteristics for devices with traditional and gradual junction profile. Compared with the device with traditional structure, the device with gradual junction profile has better V_{BD} which is improved by about 1V. This improvement can be explained by TCAD simulation results in Fig. 2. At the same drain voltage (V_D), the device with gradual junction profile has smaller electrical field (~3.4%) in cutline A-A" than the device with traditional structure, leading to improved V_{BD}.

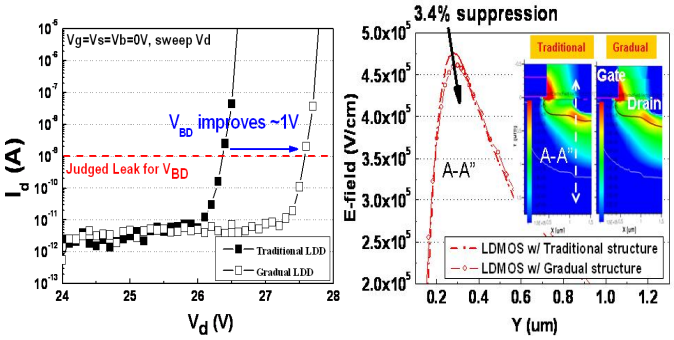

Fig. 2, Comparison of V_{BD} data and E-field simulation results.

Fig. 3 shows substrate current (I_{SUB}) vs. gate voltage (V_G) characteristics under V_D = 12V, 13V, and 14V. At V_G is roughly 3V, the value of first I_{SUB} peak is about the same between devices with traditional and gradual junction profile. As the V_G is greater than roughly 6V, Kirk effect is becoming significant and I_{SUB} rises again. Such Kirk effect induced I_{SUB} rise is less severe in the device with gradual junction profile. The suppression of Kirk effect can be explained by TCAD simulation results. As seen in Fig. 3, at V_D = 14V and V_G = 7V, the device with gradual junction profile has smaller I-I rate, leading to smaller I_{SUB}.

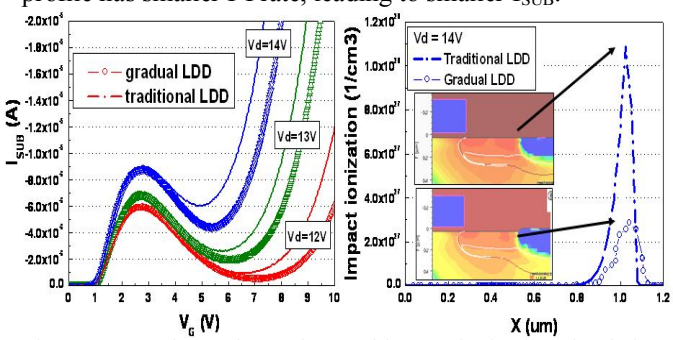

Fig. 3, Comparison of I_{SUB} data and impact ionization simulation results.

Since the device with gradual junction profile can suppress Kirk effect and leads to smaller I_{SUB} at high V_G bias, hot-carrier reliability of this device is likely to be improved. Fig. 4 shows the device parameter degradation of two kinds of device under 5000s of hot-carrier stress. The device parameters monitored are Ron and drivability current (I_{Dsat}) which are measured at V_D = 0.1V and V_D = 8V, respectively. For devices stressed under the same V_D and V_G (V_D = 14V, V_G = 6V), the device with gradual junction profile shows smaller Ron and I_{Dsat} degradation. This result suggests that reduced I_{SUB} (under the same V_G) caused by suppression of I-I rate improves hot-carrier reliability. In order to realize the relation between I_{SUB} and device degradation, Fig. 4 also shows the amount of device degradation under 5000s stress for devices stressed at V_G bias (6V, 7V, and 7.5V) such that I_{SUB} rise caused by Kirk effect is significant. Stress data show that for devices stressed under the same I_{SUB}, the device with gradual junction profile produces more device degradation than the device with traditional structure. Remember that higher V_G bias is needed for the device with gradual junction profile to produce the same I_{SUB} (due to the suppression of Kirk effect). Thus, higher V_G results in more electron injection to the gate oxide, leading to more device degradation [2].

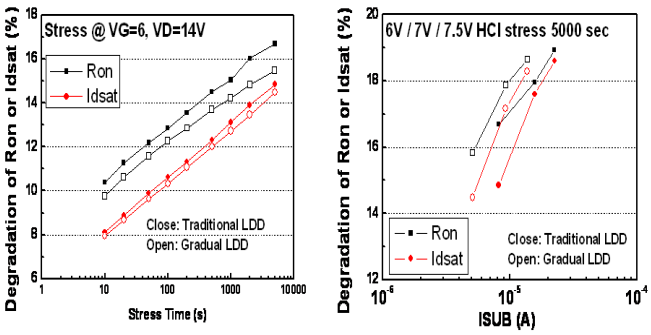

Fig. 4, Comparison of device degradation data under hot-carrier stress.

Finally, the E-SOA of devices with traditional and gradual junction structures is investigated. Fig. 5(a) depicts the measurement setting to obtain E-SOA, where different V_G steps and 100ns pulse of V_D are applied to the device. The breakdown points are judged at a given V_G and pulsed V_D which causes device burned. Results in Fig. 5(b) reveal that the device with gradual junction profile has wider E-SOA range than the device with traditional structure. Improvement of E-SOA range is suggested to be caused by suppression of I_{SUB} and better latch-up behavior.

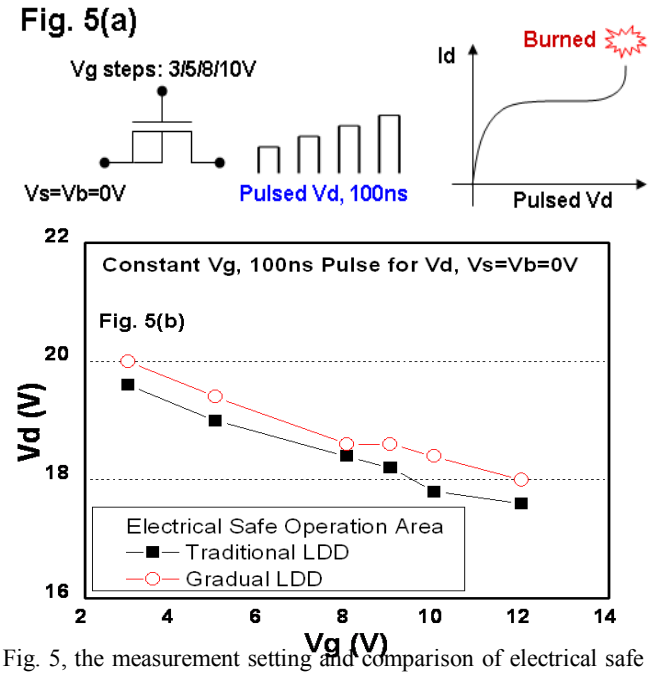

Fig. 5, the measurement setting and comparison of electrical safe operation area (E-SOA) data.

3. Conclusions

A simple mask modification which produces gradual screen oxide structure can be utilized to fabricate LDMOS devices with gradual junction profile in the N- region. In off-state operation, the device with gradual junction structure shows roughly 1V improvement in V_{BD} due to suppression of electrical field. In on-state operation, the device with gradual junction structure has less Kirk effect induced I_{SUB} rise due to suppression of I-I rate. For hot-carrier stress under the same V_G bias, the device with gradual junction structure exhibits less device parameter degradation due to suppression of I-I rate. For hot-carrier stress under the same I_{SUB}, however, the device with gradual junction structure produces worse device degradation. The reason responsible for this phenomenon is that higher V_G is needed to produce the same I_{SUB}, leading to more electron injection to the gate oxide. Finally, experimental data show that the device with gradual junction structure has wider E-SOA range than the device with traditional structure.

Acknowledgements

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References

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