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#### Latch-up Suppressed IGBT by the Deep P<sup>+</sup> Ion Implantation under the n<sup>+</sup> Source

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A novel IGBT structure, which employs the self aligned deep p+ buried region enveloping all the area under the n+ source, is proposed and verifed by SUPREM4 and PISCES-2B simulation. The latch-up current of the proposed device is found to increase with the ion implantation dose and the latch up current increases up about 10 times compared with the coventional structure when the implantation dose of the p+ buried region and the p-body is  $1 \times 10^{15}$  cm<sup>-2</sup> and  $1 \times 10^{14}$  cm<sup>-2</sup>, respectively. It should be noted that the variation of the threshold voltage is within 0.1V although the implantation dose of the p+ buried region increases from  $1 \times 10^{14}$  cm<sup>-2</sup> to  $1 \times 10^{15}$  cm<sup>-2</sup>.

### 1. Introducion

The Insulated Gate Bipolar Transistor (IGBT) is a promising device for power electronics applications due to a low voltage drop and high switching speed.<sup>1-2)</sup> However, a limited problem of the IGBT is that they include a parastic thyristor like PNPN struct that can be latched into a state where gate control is lost and the destroyed. The maximum device may be controllable current of IGBT is limited by the latch-up. It is well known that the latch-up of IGBT is caused by a voltage drop in the p-body layer under the n+ source. It has been already reported that the reduced body resistance due to the p++ diffusion, may enhance the latch-up current capability<sup>3)</sup>. But the p++ diffusion may be rather difficult to reach the outer edge of the n+ source without the increasing of the threshld voltage.

Recently, it is reported that the shallow retrograde p+ buried layer under the n+ source may suppress the latch-up considerably<sup>4</sup>. However, it may be rather troublesome to control the threshold voltage because the lateral diffusion of the Boron from the shallow p+ buried layer into the channel region during the post process may cause the shift of the threshold voltage.

In our work, we proposed a novel IGBT structure with high latch-up capability, which employs the self aligned deep p+ buried region enveloping all the area under the n+ source, is proposed and verified by the rigorous SUPREM IV and PISCES-IIB simulation.

# 2. Process Simulation

The process of the proposed device structure with the p+ buried region is simulated by SUPREM IV as follows. On a epi wafer for IGBT, the p++ diffusion and p body diffusion is performed similar to the conventional device and the high ion implantation for the deep p+ buried region is successively carried out with the same mask for p+ buried region and p body.



Fig.1 The SUPREM 4 simulation results of IGBT with the deep p+ buried region.

High energy implantation (several hundreds of KeV) was used in order that p+ buried region might be formed deep under the n+ region (more than 1 um). One micrometer thickness of oxide film is added to the masking oxide for the conventional srtucture so that the boron implanted by high energy may not penetrate into the surface of Si (n - epi region) through the oxide film and poly gate. The annealing is performed for 40 minutes at 1100 °C to recover the damage of the surface due to the high energy implantation. The rest of the proposed IGBT processes are the same as those of the conventional device.

An accurate device structure such as junction formation and deep p+ buried region is obtained from SUPREM IV as shown in Fig.1.

In Fig.2(a), 2.(b) are illustrated the doping concentration profiles before, and after the annealing propocess followed by the p+ deep ion implantation respectively. The inner most coutour of the p body shows the boundary of the doping concentration of 10<sup>18</sup> cm<sup>-3</sup> It is . ascertained that the p+ buried region envelops most of the p-body area which causes the latch-up. However, the region does not affect the channel area because the region is formed deep under the n+ source as shown in Fig.1.

Fig.3(a) and 3(b) show that the vertical doping profile of the conventional and the proposed device structure respectively. The doping level of the p-body in the proposed device is much higher than that of the p-body in the conventional device.

The lateral profiles of the conventional and proposed device structures are shown in Fig.4(a). and 4(b). From that figures, we can see that the doping profiles of the channel region are almost the same .



Fig.3 Vertical doping profile of the conventional structure (a) and the novel structure with the deep p+ buried region (b).





Fig.2 Doping concentration contour before the ion implantation for the deep p+ buried region (a) and after the annealing process followed by the ion implantation for the deep p+ buried region (b).

Fig.4 Lateral doping profile of the conventional structure (a) and the novel structure with deep p+ buried region (b).

# 3. Device Simulation

The intensive device simulation was performed to evaluate the characteristics of the proposed simulator 2-D device the IGBT with The simulated device MEDICI(PISCES IIB) . structure was created by SUPREM IV as described above. We were able to evaluate the latch-up current density and the threshold voltage of the device from the simulation results.

It is shown in Fig.5 that the latch-up current increases up to about 10 times compared with the conventional structure when the ion implantation dose of the p+ buried region and the p-body is  $1\times10^{15}$  cm<sup>-2</sup> and  $1\times10^{14}$  cm<sup>-2</sup> respectively. This trend is the consequence expected from the fact that, as the doping of the p-body grows high, the resistance of the p body decreases . However, the merit of our structure is that the Increased p-body resistance by the deep p+ diffusion does not shift the threshold voltage.

It should be noted that the variation of the threshold voltage is within 0.1 V although the implantation dose of the p+ buried region increases from  $1 \times 10^{14}$  cm<sup>-2</sup> to  $1 \times 10^{15}$  cm<sup>-2</sup>.

It is ascertained in Fig.6 that the deep p+ buried region does not cause the shift of the threshold voltage when the Ion implantation energy exceeds a certain level. Therefore, in order to get the controllable Vth, more energy is required with the increasing of the dose of the p+ buried region.

As an example, the I-V curve of the proposed IGBT, which is implanted with energy of 500 keV and p+ dose of  $5\times10^{14}$ cm<sup>-2</sup>, is shown in Fig.7. The latch-up of our device increases about 5 times compared with the coventional structure.

## 4. Conclusion

we propose a new IGBT structure employing the deep p+ buried layer under the n+ source and verify the improvement of the latch-up characteristics by the numerical simulation. In the proposed structure, the latch-up current increases up to 10 times without sacrificing any other characteristics.



Fig.5 Latch-up current density and  $V_{\rm th}$  with various ion implantation dose.

Dose=0 indicates the conventional structure.

### Reference

- M. Nishhara, "Power Electronics Diversity", Proc. Int. Power Electronics Conf. (1990) 22.
- B.J.Baliga, "Power Semiconductor Devices for the 1990's" Proc. EPE-MADEP'91 (1991) 1.
- B.J.Baliga, "The Insiluated Gate Transistor: A New Three-Terminal MOS-Controlled Bipolar Power Device", IEEE Trans. Electron Device 31 (1984) 192.
- S.Eranen & M.Blomberg,"The Vertical IGBT with An Implanted Buried Layer", ISPSD 1991 Technical Digest(1991) 211.



Fig.6  $V_{th}$  vs implantation energy for the case of the deep p+ dose of 1E14 cm<sup>-2</sup> and 5E14 cm<sup>-2</sup>.



Fig.7 Comparison of latch up characteristic of IGBT with deep p+ buried region and conventional IGBT.

- \* Implantation energy and implantation dose for the deep p+ buried region are 500 keV and 5E14 cm<sup>-2</sup> Respectively.
- o Conventional IGBT without the deep p+ buried region (Implantation energy and implantation dose for the p-body are 40 keV and 1E14 cm<sup>-2</sup> Respectively.)